PHYSICS

Physics

By

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PHYSICS
Parts 1–2

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NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

PHYSICS, PART 1

PHYSICS, PART 2

PHYSICS
(PART 1)

MATTER AND ITS PROPERTIES

GENERAL PROPERTIES OF MATTER

DEFINITIONS

1. Introductory.—In general it may be stated that science deals with the behavior of matter under all of the conditions to which it may be subjected, and with the laws governing its behavior. Matter has been defined as anything that occupies space and has weight. Thus, gases, liquids, and solids all conform to this definition of the term. However, matter is best described by its properties. Different kinds of matter are called *substances;* thus, sugar, salt, wood, and steel are substances.

2. Science is divided into numerous branches, among which may be mentioned geology, which treats of rock formation, and biology, which treats of plant and animal life. That branch of science which is called physics is concerned with changes in the form and state of matter, or, in general, with changes that ordinarly do not affect the composition of matter. Thus, when ice is melted and the water formed is converted into steam, three different states of matter are observed; but the composition of all is identical. Again, iron may be melted, but the liquid has the same composition

as the solid material. Changes that affect the composition of matter will be considered under the subject of chemistry.

3. Divisibility of Matter.—Matter may be divided into parts or particles by mechanical means; thus, a crystal of salt may be divided into two parts and each of these parts may be subdivided and the process of division repeated as far as mechanical appliances will permit. If these apparently small particles of salt are placed under a powerful magnifying glass or under a microscope the possibility of further subdivision becomes readily apparent.

4. Molecules.—The view was once held that there was no limit, theoretically, beyond which matter could not be subdivided. This theory has been discarded and the view taken that matter is composed of extremely small particles, and that if these small particles could be obtained by mechanical means, further subdivision by mechanical or physical means would be impossible. These small particles are supposed to have the same properties as the substances from which they are derived and they are called *molecules*. It should be realized, however, that molecules are merely assumed to exist. They have never actually been isolated, and their actual size, weight, and shape are problematical.

5. Atoms.—Although it is true that the molecule has never been subdivided by mechanical means, its subdivision can be easily accomplished by methods peculiar to the science of chemistry. The molecule of salt, for instance, can be readily resolved into its component parts, and these have been found to consist of the two substances, chlorine and sodium. Thus, it is possible to conceive of the molecule of salt as having been divided by chemical means into two parts or particles. These particles are called *atoms*. From this it must not be understood that single atoms or molecules can be handled or worked with, but they can be handled in the aggregate. Thus, a lump of salt contains an infinite number of salt molecules, each of which in turn is made up of one sodium and one chlorine atom.

6. Electrons.—Working on the supposition that the structure of all matter is electrical, several eminent physicists have within recent years shown that the atom can be broken down to an extent which indicates that it is made up of a nucleus consisting of particles charged with one kind of electricity, surrounded by particles called *electrons,* which are charged with a different kind of electricity.* The number of electrons varies for each substance that the chemist now regards as an element. Gold, silver, iron, copper, and lead are common elements.

7. Indestructibility of Matter.—Before the existence of electrons was demonstrated, it was assumed that atoms were unalterable particles of matter and that for this reason matter was indestructible. According to this viewpoint a body might undergo thousands of changes; it might be resolved into its molecules and its molecules might be resolved into atoms; these atoms might then unite with other atoms to form other molecules and bodies that would be entirely different from the original body; but through all these changes the number of atoms was supposed to remain the same. Thus, the sum total of the atoms of the universe was supposed to be exactly the same as it was at the beginning of time and it was stated that it would always remain the same.

8. Matter cannot be destroyed, and no evidence has yet been brought forth to disprove the accepted ideas on this subject. The fact that the atom can be altered has, however, been demonstrated; and what has usually been said concerning the indestructibility of matter must be modified. Thus, the sum total of the atoms present in the universe may be constantly changing because of the disintegration of atoms. The process of disintegration takes place very slowly with most elements; but it occurs with such rapidity in the case of radium that it may actually be observed. Our present conception of the indestructibility of matter is, therefore,

*The different kinds of electricity are called *positive* and *negative.* The origin of these terms is taken up later.

that while the atom may be altered, the sum total of electrons remains the same, no matter what changes the atom undergoes.

9. Volume, Mass, and Weight.—By volume is meant the quantity of space that a body occupies. This space is determined by the length, width, and thickness of the body. By mass is meant the quantity of matter in a body. The mass of any given body may be regarded as a constant. It does not vary, although its volume may. Thus, a quantity of matter, such as a bale of cotton, which occupies a certain space or volume, may be subjected to such a pressure that its volume is decreased by one-half. The quantity of cotton in the bale remains the same, however. Weight is the result of the attractive force or pull that the earth exerts on all bodies. This attractive force is better known as the force of gravity, and the pull that it exerts on a body varies with that body's distance from the center of the earth. Weight is therefore a variable and not a constant quantity. Thus, a quantity of matter that weighs a pound on the earth's surface will weigh somewhat less at the top of a high mountain.

10. Finding Weight of Matter.—The balance illustrated in Fig. 1 (a) is a type that is constantly used by physicists and chemists for weighing purposes. It has a capacity of 200 grams and is sensitive to a weight of one-tenth of a milligram. To exclude dust and air currents when weighing, it is enclosed in a glass case, the front and back parts of which are sliding doors that may be raised. At the top of the hollow pillar a is embedded a rectangular piece b of agate, on which rest the agate knife edges c of the beam d. The stirrups e, from which the scale pans f are suspended, also rest on agate knife edges. At g is shown the leveling screw by which the case may be adjusted so as to bring the air bubble in the spirit level h into a central position. The knob i operates a rod, placed in the pillar a, by means of which the beam may be lifted slightly off its bearings, or knife edges. This is the position to be occupied by the beam when the balance is not in use. By turning the knob i in the required direction, in this case to
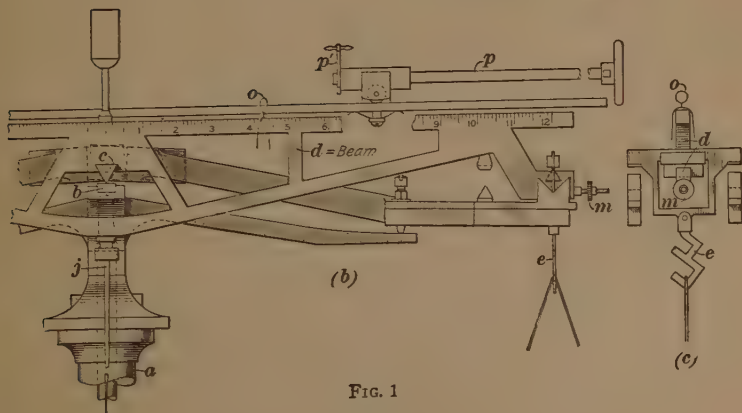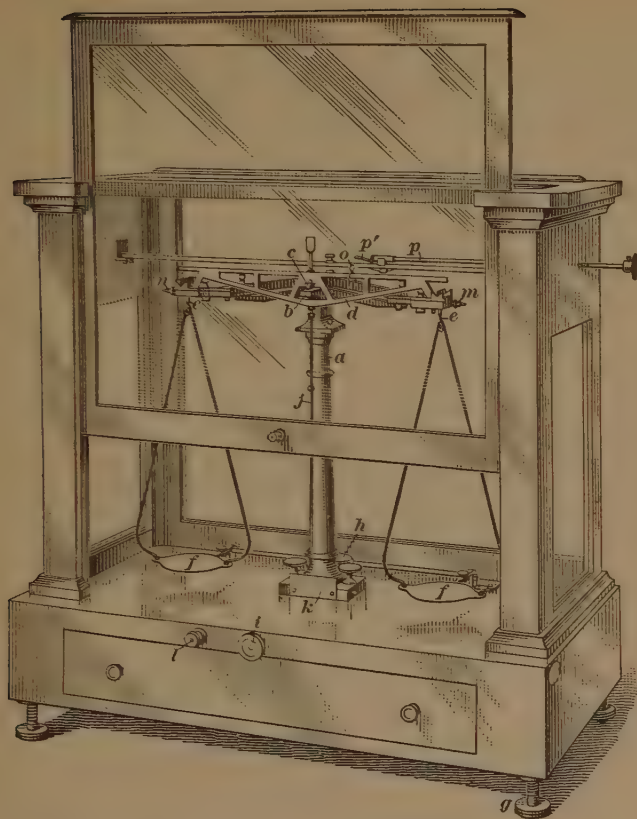
FIG. 1

the left, the beam is lowered upon its knife edges and the balance is ready for weighing operations, provided that the balance pans have been balanced with respect to each other.

11. To ascertain whether the two pans *f*, Fig. 1 (*a*), are in perfect balance, see whether the pointer, or index *j*, comes to rest at the zero mark of the scale *k*, when the beam and scale pans are released. The beam is released by turning the knob *i* to the left and the scale pans are released by pushing in the knob *l* and turning it to the right. The beam and the pans are now free to swing, and if the pointer moves over the same number of scale divisions on either side of the zero mark it indicates that the pans are in balance. Should the pointer swing farther to the left of the zero mark, the right-hand pan is too heavy and balance must be established by means of the screws *m* and *n*. In this case the screw *m* should be turned so as to bring it nearer the pillar *a*; or, the screw *n* should be turned in the same direction, thus bringing it farther away from *a*. Either of the screws should be given only a few turns at a time, testing the results and repeating the operations until the pointer swings over the same number of divisions on either side of the zero mark, coming finally to rest at this point. In (*b*) is an enlarged view of the right-hand end of the beam partly broken away. In this view the rider *o* is clearly shown, as well as the arm *p'* on the rod *p* by which the rider is moved into position. At the end of the beam is seen the adjusting screw *m*. In (*c*) is an end view of the beam, corresponding parts in all the views being indicated by similar letters.

12. The operation of weighing consists in placing the substance to be weighed on the left-hand scale pan and the required number of weights on the other scale pan to produce a balance between the two pans and thus compel the pointer to come to rest at the zero mark. The smallest separate weight that may be used for the right-hand pan weighs 1 milligram. Ordinarily, however, when it is necessary to use less than a 10-milligram weight, the platinum rider *o* shown resting on the beam *d*, Fig. 1, is used. This rider weighs 12 milligrams, and is known as a 12-milligram rider. When placed on the beam

at the division marked *10*, it produces the same effect as a 10-milligram weight placed on the right-hand pan. If the rider is moved to the division *1* on the beam or to any other division up to *12*, the effect produced corresponds with that obtained by placing a corresponding number of milligrams on the right-hand pan. In some balances there is a rider for each end of the beam, and either one may be placed in position by means of the rods *p*.

13. The weights are usually kept in a box, as shown in Fig. 2. The larger weights are generally made of brass and sometimes gold-plated; the smaller ones are made of aluminum
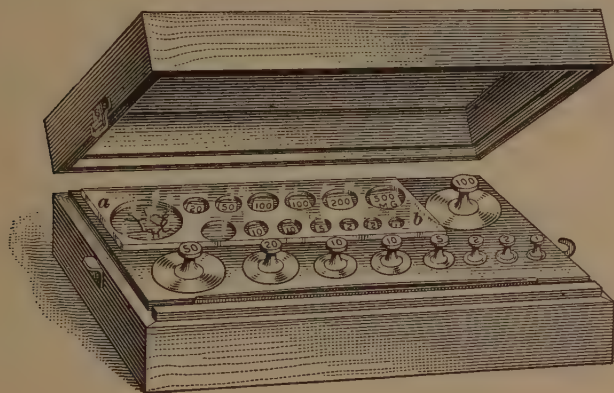
Fig. 2

or platinum. Each small weight rests in a separate compartment under a glass lid *a b*. For the purpose of lifting the weights, a forceps is used, which has its place in a slot at the front of the box. Accurate weights must under no consideration be touched with the fingers, but always lifted with the forceps. The arrangement of the weights varies with different makes, but the illustration shows the usual and most convenient arrangement for a set of weights of from 100 grams to .0001 gram.

Before attempting to weigh, the beginner must learn not only the denomination of each weight, but also its place in the box. He must be able to read the weights he has placed on the bal-

ance pan by observing the empty spaces in the box as well as by observing the weights themselves.

14. States of Matter.—In order to explain the behavior of matter under all sorts of conditions, such as those resulting from the application of heat and pressure, it is assumed that matter is made up of molecules. Matter exists in three states, namely, solid, liquid, and gaseous. The basis of this classification is the relative freedom with which the molecules of matter move about or vibrate and the property of mutual attraction that they possess. The property to attract and hold one another together is called *cohesion* for molecules of the same kind, or like molecules, and *adhesion* when attraction is exerted between dissimilar, or unlike, molecules.

15. In each of the three states of matter mentioned, it is assumed that the molecules are continually in a state of motion, or constantly vibrating to and fro. In a solid the molecules are held closely together and kept from getting away from one another by cohesion. They are separated from one another, however, by distances that are considerably greater than their own diameters. In liquids, the distance through which a molecule may move is increased and the cohesive forces that bind the molecules together are lessened. In gases, the molecular vibrations have increased to such an extent that the distance between any two molecules has become too great for the cohesive forces to become effective. The molecules, therefore, follow independent paths and constantly collide and rebound in every direction.

16. Changes of State.—Some substances pass from one state to another under changes of temperature and pressure. If, for example, a piece of ice, a solid, is heated sufficiently, it melts and forms water, a liquid. The molecules of ice firmly held together by cohesive forces can retain their original positions without being supported by some external rigid body; that is, a piece of ice will retain its shape without being supported by some vessel such as a cup or a box. The molecules of water, on the other hand, attract one another to a lesser

degree than those of ice and are held together loosely. There-
fore, some external rigid container, such as a cup or a glass,
is needed to hold the liquid in position. Water held in a cer-
tain shape by a container will not keep that shape when poured
into a container of another shape, but will assume the shape of
the second container. If water is heated to a sufficiently high
temperature, it forms a gas known as steam. The molecules
of steam tend to follow independent paths and fly off into
space, unless held in a closed vessel. The term *vapor* is some-
times used to refer to a substance that at ordinary temperatures
is either a solid or a liquid, but that has been changed to a gas
by the application of heat.

EXAMPLES OF GENERAL PROPERTIES

17. Impenetrability.—Properties that are common to all
kinds of matter, whether in the solid, liquid, or gaseous state,
are called general properties, and a few of these will be
described. For instance, when a certain space is occupied by
a body, the same space cannot be occupied by another body at
the same time. This property, known as impenetrability, is
obviously possessed by solids, liquids, and gases. Thus, if a
solid body is put into a vessel already full of a liquid, the
latter overflows and the same thing occurs if more of the liquid
is introduced.

18. Porosity.—All matter is probably porous to a greater
or less extent and apparent exceptions to the rule of impenetra-
bility may be explained by means of this property. Porosity is
accounted for by the assumption that the molecules of a sub-
stance are not in actual contact, but are separated from each
other by spaces that are relatively large as compared with the
size of the molecules. Thus, when some substances are put
into a vessel containing a liquid, no appreciable increase in vol-
ume will be noted. In such a case the liquid occupies the pores
of the substance added.

19. The phenomenon of porosity is illustrated when an
under-burned brick is placed in a vessel of water, or when

certain liquids, such as alcohol and water, are mixed. In the latter example, if equal quantities of the liquids are mixed, the resulting volume of the mixture will be somewhat less than twice the volume of either the alcohol or the water. The existence of pores is further emphasized by the fact that all matter is compressible, that is, its volume may be diminished by pressure. Pores are designated as being *sensible,* or those which can be actually seen with or without the aid of the microscope, and *physical,* or those which are invisible and are assumed to exist.

20. Compressibility.—The extent to which a substance may be compressed depends on the physical state of the substance. Solids are compressible by reason of both the sensible and physical pores that are a part of their structure. Liquids are only slightly compressible because the spaces that exist between the molecules are small; and if, in some manner, the sensible and physical pores of solids could be eliminated, it could probably be shown that solids are even less compressible than liquids. Gases are the most compressible of all substances, which is to be expected because of the comparatively large spaces that are assumed to exist between their molecules.

21. Elasticity.—Elasticity is that property of matter by virtue of which it tends to resume its original shape when the distorting force is removed. Liquids, to the extent that they are compressible, are also elastic. The degree of elasticity of solids varies over a wide range. Thus, glass, steel, and rubber are extremely elastic, whereas a piece of lead possesses this property to only a slight degree.

22. Energy.—Energy may be defined as the capacity for doing work; thus, work is done when a body is raised against the resistance of the force of gravity from a lower to a higher level. Work is again done when a spring is coiled, as when a watch or a clock is wound. The raised body and the coiled spring are sources of energy and in turn may do work in overcoming resistance. Energy may appear in a number of different forms, among which may be mentioned heat, light, and electricity.

23.   Inertia.—By the inertia of a body is meant that property by virtue of which it tends to remain in its state of rest or motion in a straight line. If it is in a state of rest it will remain so until acted upon by some external influence or force. If it is in motion it will continue to move until brought to a state of rest by a force. Examples of inertia are seen when coal is shoveled into a furnace or when a cloth is suddenly pulled from beneath a heavy body. The inertia of the coal in the one instance causes it to leave the shovel as the motion of the latter is suddenly arrested. In the second instance, the inertia of the heavy body prevents its being pulled along with the cloth.

24.   Centrifugal Force.—Force has been defined as the cause of change of motion; or, it is that which, by acting upon a body, tends to produce or arrest motion. The effects of a particular kind of force, called centrifugal force, are illustrated by the following examples: If a heavy weight is attached to a string and whirled around in a circle, it has a constant tendency to fly off in a straight line and this is what actually happens if the string breaks. Again, water adhering to a rotating wheel leaves the latter just as soon as the centrifugal force, which increases with the rate of rotation of the wheel, becomes stronger than the adhesion of the water. The breaking of rapidly revolving grinding wheels and the skidding of an automobile that rounds a curve at too high a speed are examples of the action of centrifugal force.

25.   The application of centrifugal force in which the chemist is particularly interested is seen in certain machines and pieces of apparatus used in chemical plants and laboratories for drying purposes and for separating liquids from solids. Thus, in sugar refineries, centrifugal machines are used to separate the crystallized sugar from the syrup; in dairies the same principle is used in separating the cream from the milk; in the laboratory a small machine called a *centrifuge,* operated by hand power or by means of a small motor, is used in milk analysis or as a means of breaking up troublesome emulsions. A commonly used type of centrifugal machine or *wringer,*

as it is sometimes called, consists of a metal basket about 40 inches in diameter and closely perforated around the sides. The material to be treated is placed in this basket, which is mounted on a vertical shaft that revolves at any required rate up to about 2,500 revolutions per minute. This rate of rotation will effectually cause the separation of syrup from sugar crystals, etc. The basket is enclosed by a cast-iron or steel housing that catches the liquid which separates from the solid.

SPECIAL PROPERTIES OF MATTER

PROPERTIES OF SOLIDS

26. Hardness.—Hardness is the resistance offered by a body to scratching or abrasion. The diamond possesses a greater degree of hardness than any other known body. It can be ground and polished only by the use of diamond dust. Other hard substances used as abrasives and polishing agents are carborundum, emery, and tripoli. The property of hardness may be imparted to certain kinds of steel when it is suddenly cooled down from a high temperature by dipping it into water or oil.

27. Brittleness.—A substance is said to be brittle if it breaks or is easily crushed when subjected to the action of forces that tend to compress or bend it; thus, glass, celluloid, and ordinary rosin are classed as brittle. The property of hardness is sometimes accompanied by that of brittleness; thus, the diamond is both hard and brittle.

28. Tenacity.—Tenacity is the resistance a body offers to forces that tend to tear it apart. Of the solid metals, lead has probably the least tenacity, and certain kinds of steel have the greatest tenacity. Silk and cotton fibers possess this property to a high degree.

29. Ductility.—Ductility is that property of a body by virtue of which it may be drawn out into fine wires, threads, or

filaments. Platinum, gold, silver, and copper are very ductile. Some substances, such as glass and quartz, are ductile only at high temperatures.

30. Malleability.—Malleability is that property of a substance which permits it to be rolled or hammered out into thin sheets. Most substances that are ductile at ordinary temperatures are also malleable, but the contrary is not true; thus, platinum, gold, silver, and copper are ductile and also malleable; but although lead and tin are malleable, they are not extremely ductile.

PROPERTIES OF LIQUIDS

31. General Characteristics.—A liquid does not possess a shape of its own, but adjusts itself to the shape of the containing vessel. From this it must not be supposed, however, that the molecules of a liquid do not exert certain forces upon one another. In fact, the contrary may easily be shown to be true. Thus, if a small glass plate is suspended in a horizontal position, from one arm of a balance, as shown at a, Fig. 3, and its weight is then exactly counterbalanced by placing weights on the opposite pan, a very small force acting on either balance arm will destroy the equilibrium that exists.

If a small vessel of water is now placed carefully under the glass plate and raised until the surface of the water just comes in contact with the under surface of the plate, equilibrium will be destroyed and it will be found necessary to place additional weights on the balance pan in order to raise
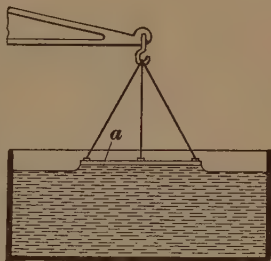

FIG. 3

the glass from the water. On examination of the plate, a water layer will be found on its under surface, and this indicates that the force used to raise the glass plate from the water was expended in overcoming the cohesive forces existing between the molecules of water, and not in pulling the glass away from the water.

32. Viscosity.—Every one realizes that certain liquids flow more readily than others; thus, water can be poured from a container much more rapidly than can a heavy lubricating oil. The resistance offered by a liquid to any force that tends to make it flow is called its viscosity. This property is assumed to be due to friction between the molecules and also to the attraction that the molecules have for each other. Comparative viscosities form a valuable means of testing lubricating oils in order to determine whether or not the product will pass certain specifications.

33. Capillary Phenomena.—When the glass plate in Fig. 3 was raised from the surface of the water, a layer of water adhered to the glass, showing that the molecules of the glass exerted on the water molecules an adhesive force that overcame the cohesive forces existing between the molecules of the liquid. If a clean glass rod is dipped in water, as in Fig. 4 (*a*), it will be wet, as was the glass plate, and some of the water will adhere to it. On the other hand, if the clean dry rod is dipped in mercury, as in (*b*), it will not be wet when removed and none of the mercury will adhere to it.

34. If a series of glass capillary tubes—which are tubes of small diameter varying from .1 millimeter to 2 millimeters— are substituted for the glass rod in Fig. 4(*a*) and (*b*), the phenomenon of *capillarity* will be illustrated. Thus, in (*c*) it is seen that water rises to a different height in each tube, depending on the internal diameter of the tube, while mercury is depressed as shown in (*d*), the extent of the depression likewise depending on the diameter of the tube. As a result of this experiment, it may be stated that liquids rise in capillary tubes when the latter are wetted and that liquids are depressed in capillary tubes when they are not wetted. The extent of the elevation or depression that occurs depends on the liquid used, but for any given liquid it is inversely proportional to the diameters of the tubes.

35. It will be noticed, in Fig. 4 (*d*), that the surface of the mercury in the capillary tubes is convex while the surface of

the water in the tubes in (c) is concave. This is an illustration of an actual fact and is explained by considering the strength of the adhesive forces that act between the wall of the tube and the liquid and the strength of the cohesive forces in the liquid. Thus, when the adhesive force between the glass wall and the liquid is stronger than the cohesive force between the molecules of the liquid, the latter wets the tube and rises in it. In

(a)   (b)   (c)   (d)
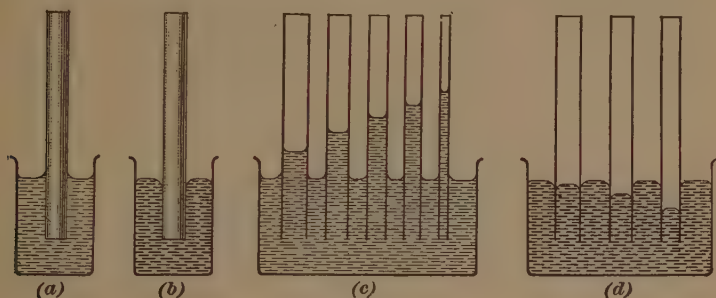
Fig. 4

the case of mercury, the cohesive force is stronger than the adhesive force; thus, the liquid does not wet the tube and is depressed.

36. Examples of Capillary Action.—Capillary phenomena are in evidence everywhere, and are not only witnessed in the laboratory. Thus, the absorption of water by a lump of sugar, of ink by a blotter, and of oil by a wick are familiar examples.

37. Surface Tension.—Experiment shows that the surface of a liquid possesses physical properties different from those of the interior portion of the liquid. If a small needle is very carefully placed on the surface of water, it will float, although it is much heavier than the small quantity of water that it would displace on being immersed. The surface of the water acts as a tough membrane, and if the floating needle and the surface of the water are closely examined, the surface will be found to be indented or depressed where the needle rests on it. This phenomenon is due to the surface tension of the water, which may be explained in the same manner as the

phenomenon of capillarity. In this case the liquid does not wet the needle, and the cohesive force existing between the molecules at the surface is greater than the adhesive force between the needle and the water.

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TRANSMISSION OF PRESSURE BY LIQUIDS

38. Pressure in Liquids.—When a pressure is applied to an enclosed liquid, the same pressure is transmitted equally in all directions throughout the liquid and to the sides of the containing vessel. This statement of a fact is due to Pascal, who was a French scientist of the 17th century, and its truth can easily be demonstrated. Thus, if a vessel has the shape shown in Fig. 5, any pressure applied to the piston a will be trans-

FIG. 5

mitted to the piston b. If the pistons are regarded as having no weight, and their areas exposed to the water are 1 square inch and 100 square inches, respectively, a pressure of 1 pound downwards on the piston a will exactly balance a downward pressure of 100 pounds on the piston b. Then, if the pressure on the piston a is increased slightly, and no water escapes past it, the pressure of 100 pounds on the piston b will be overcome and it will be forced upwards.
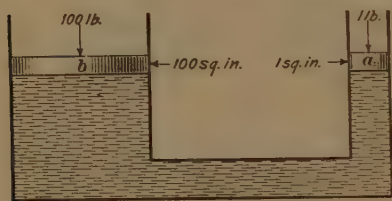
39. Hydraulic Press.—An important application of Pascal's principle is found in the hydraulic press shown in Fig. 6. The press represents a mechanical means of accomplishing results similar to those described in connection with Fig. 5. As shown in Fig. 6, the small piston a is moved by the hand lever b. When the lever is raised, the valve f closes and the valve c opens, admitting oil from the reservoir e into the chamber d. Then, when the lever b is pushed down, the piston a exerts a pressure on the oil, which closes the valve c and opens the valve f. The pressure exerted is then transmitted to the piston g. The pipe h admits oil to the reservoir e.

40. At first glance it might seem that more work is done by the large piston g, Fig. 6, than is put into the small piston a, but this is not the case. If the area of the piston a is 1 square inch and that of the piston g is 100 square inches, a pressure of 1 pound exerted by the piston a will cause the piston g to exert a pressure of 100 pounds; but if the piston a moves through a distance of 10 inches in making its downward stroke, the piston g will be raised only $\frac{1}{10}$ inch. Therefore, it will take ten 10-inch strokes of the piston a to raise the piston g 1 inch. Stated in other words, it requires just as much work to raise 1 pound through a distance of 100 inches as it does to raise 100 pounds through a distance of 1 inch. Other machines operated by hydraulic pressure find extensive application in all kinds of engineering.
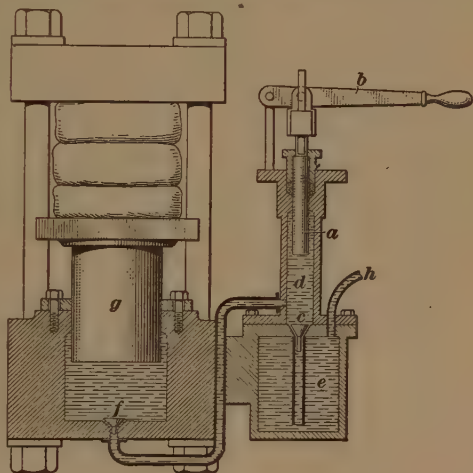
FIG. 6

41. Principle of Archimedes.—It is a well-known fact that liquids in general have a buoyant effect, or exert an upward pressure, on all bodies placed in them. Some bodies, such as pieces of iron or rock, will sink when placed in water, while others, such as wood or cork, will float. When a body does not float, it is an easy matter to show that it has apparently lost weight, simply by weighing it in and out of water. The upward force exerted by a liquid upon a body floating on its surface or immersed in it, is called buoyancy. The law of buoyancy was discovered about the year 240 B. C. by Archimedes, a Greek philosopher. It may be stated as follows: *The loss of weight of a body submerged in a liquid is equal to the weight of the liquid displaced by the body.*

42. If a body is dropped into a graduated vessel containing 50 cubic centimeters of water, and the water rises or is displaced so that the vessel apparently contains 51 cubic centimeters, it is evident that the body has displaced 1 cubic centimeter of water. This quantity of water at 4° C. weighs 1 gram. Therefore, the body must have suffered a loss in weight of 1 gram if the water was at a temperature of 4° C. That the law of buoyancy is a statement of a fact can also be shown by the use of a balance.

SPECIFIC GRAVITY

DEFINITIONS

43. By *specific gravity* is meant the weight of a body compared with the weight of an equal volume of water. The specific gravity of water is used as the standard for purposes of comparison and has been given the value 1. The specific gravity of a substance is an abstract number; thus, if a certain volume of a substance weighs 10 grams and a like volume of water weighs 1 gram, the specific gravity of the substance is 10. The *density* of a substance, however,—its weight per unit volume,—is a concrete number. Thus if the volume of the solid just mentioned were 1 cubic centimeter, and it weighed 10 grams, its density would be 10 grams per cubic centimeter.

44. The specific gravity of any pure solid, liquid, or gas is a constant quantity and is always expressed as an abstract number. The densities of bodies or substances, however, may be expressed in different systems. Thus, in the metric system, the density of water is 1 gram per cubic centimeter, and in this system density is numerically the same as specific gravity; but in the English system, the density of water is 62.4 pounds per cubic foot. In the metric system the density of mercury is 13.6 grams per cubic centimeter, whereas its specific gravity is simply 13.6.

45. The absolute density of a substance, or its weight per unit volume, is very seldom determined or used by the

chemist, since it is more desirable to know the weight of a substance as compared with another substance used as a standard. Thus, instead of finding the actual weight in grams of a cubic centimeter of lead, iron, etc., and using the number obtained as the density, the weight of any convenient volume of a substance is compared with the weight of a like volume of water at the same temperature, the result being expressed as its specific gravity. Then, instead of saying that a piece of lead weighs a certain number of grams it is said that its specific gravity is 11.337 at 20° C., which means that lead is 11.337 times as heavy as water at 20° C.

METHODS OF FINDING SPECIFIC GRAVITY

46. General Rule for Specific Gravity.—Since the specific gravity of a substance is merely the number obtained by comparing its weight with the weight of an equal volume of water at the same temperature, the following rule covers all determinations:

Rule.—*To find the specific gravity of a substance, weigh a sample of it and divide its weight by the weight of an equal volume of water at the same temperature.*

47. Solids Heavier Than Water.—To determine the specific gravity of a solid substance that is insoluble in water, it is only necessary to determine the weight and volume of a portion of the substance, and with these data at hand, the specific gravity may be easily calculated. The weight of the substance is readily obtained by weighing it on a balance; but if the substance is irregular in shape it would be a very difficult matter to obtain its volume by means of measurements, so the *principle of Archimedes* is applied. This principle enables one to find the volume of an irregular solid, such as a piece of rosin, as follows: The rosin is weighed in the usual manner and its weight is found to be, for instance, 20 grams. The rosin is now suspended from one beam of a balance by means of a light thread, and on a bench below it is placed a small beaker containing water, as shown in Fig. 7, the beaker

being so placed as to allow the balance pan to swing freely. While the rosin is suspended in the water its weight is again ascertained. This weight will be much less than the weight of the rosin in air. To be exact, it should weigh 1.7 grams, and the loss in weight sustained is $20-1.7=18.3$ grams. According to the principle of Archimedes, the piece of rosin has displaced a mass of water weighing 18.3 grams, which corresponds to a volume of 18.3 cubic centimeters, and this equals the volume of the rosin. The specific gravity of the rosin is therefore $20 \div 18.3 = 1.09$.
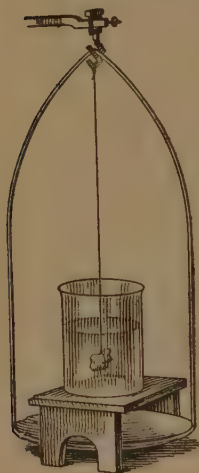
Fig. 7

48. Solids Lighter Than Water.—If the substance, the specific gravity of which is to be determined, is lighter than water, a sinker must be used. For convenience in weighing, the sinker is fastened below the substance. The beaker containing the water is then placed under the sinker and the substance and raised until the water level is above the sinker but does not touch the substance. The weight is then recorded. The beaker is next raised so that the substance is submerged, and another weighing is made. This latter weight will be less than that obtained by the first weighing because, in the second weighing, the substance is buoyed up by the water. The difference in the two weights is equal to the weight of water displaced by the substance. The weight of the substance in air divided by the weight of water which it displaces gives the specific gravity. The following illustration shows how the foregoing principle would be used in an actual determination :

A piece of cork weighs 24 grams in air, but, when it is attached to a sinker and the sinker alone is under water, the combined weight of the sinker and cork is 186 grams. When both the cork and the sinker are under water, however, their combined weight is only 86 grams. The loss in weight due to the cork is 100 grams ; or, looking at it in another way, the cork

has displaced 100 cubic centimeters of water, which weighs 100 grams. The specific gravity of the cork is, therefore, $24 \div 100 = .24$.

49. Method of Using Specific-Gravity Bottle.—The specific-gravity bottle, Fig. 8 (*a*), is made of thin glass and is fitted with a ground-glass stopper, through which runs a very narrow hole, or a capillary tube, opening into the bottle. In order to obtain the specific gravity of a substance insoluble in water, the clean dry bottle is weighed empty and again when filled with water. The bottle may be quite full; since, on fitting the stopper, any excess water will pass up through the small perforation in the stopper and may be wiped off. The difference in the two weights gives the weight of the water that fills the bottle and also the volume contained, in cubic centimeters. A few grams of the substance, the specific gravity of which is to be determined, is now introduced in the form of a powder into the empty and dried bottle, and the bottle is again weighed. Some water is next added and the contents of the bottle shaken to wet the powder thoroughly and to dislodge air bubbles; the bottle is then filled as before and again

FIG. 8

weighed. From the data obtained, the specific gravity is found as follows: The weight of the material is found by subtracting the weight of the empty bottle from the weight of the bottle containing only the powder. Then the combined weight of the bottle with the powder is subtracted from the weight of the filled bottle that also contains the powder. The difference, which is the weight of the water that surrounds the powder, is now subtracted from the weight of the water that fills the empty bottle. The difference will give the weight of the water displaced by the powder and also the volume of the powder The weight of the dry powder divided by its volume gives its specific gravity.
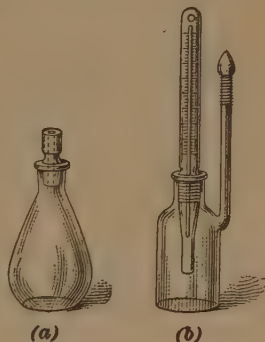
ILLUSTRATION.—The application of the preceding method for finding the specific gravity of a powder will be seen from the following:

Weight of bottle filled with water............................. 23 g.
Weight of empty bottle.. 7 g.

Weight of water.. 16 g.
Weight of powder and empty bottle............................ 10 g.
Weight of empty bottle....................................... 7 g.

Weight of powder... 3 g.
Weight of bottle containing water and powder.................24.3 g.
Weight of bottle with powder, but without water.............10.0 g.

Weight of water that surrounds the powder...............14.3 g.
Weight of whole volume of water...........................16.0 g.
Weight of water surrounding powder........................14.3 g.

Weight of water displaced by powder.................... 1.7 g.
Volume of water displaced by powder is 1.7 cubic centimeters.

Weight of dry powder divided by its volume gives its specific gravity. Or, $3 \div 1.7 = 1.765$. Ans.

50. Specific Gravity of Liquids.—The specific gravity of liquids is found more easily than that of solids. The operation consists merely in obtaining the weight of the liquid filling a specific-gravity bottle at a standard temperature and dividing this weight by the weight of the water that fills the same bottle at the same temperature. The bottle shown in Fig. 8 (b) is very convenient for this purpose, as the thermometer enables one to have the liquids at the same temperature.

51. Specific Gravity of Substances Soluble in Water. In case the substance of which the specific gravity is to be found is soluble in water, a liquid of known specific gravity is used that does not dissolve the substance, and the operation is carried out just as if water were being used. The result obtained is then multiplied by the specific gravity of the liquid, which gives the true specific gravity of the solid.

52. Application of Methods for Finding Specific Gravity. The preceding methods for finding the specific gravity of a substance will be better understood by solving the following examples:

EXAMPLE 1.—A piece of silver weighs 32 grams in air and 28.95 grams in water. What is its specific gravity?

SOLUTION.—The loss in weight is 32—28.95=3.05 g. As 3.05 g. is equivalent to 3.05 cubic centimeters, the latter value must represent its volume, or the volume of water displaced. Hence, the specific gravity is found by dividing the weight of the silver by its volume, or 32÷3.05=10.5. Ans.

EXAMPLE 2.—A specific-gravity flask contains 55 cubic centimeters of water. When filled with acetic acid the weight of the acid is 58.3 grams. What is its specific gravity?

SOLUTION.—The volume of the flask is equal to 55 cubic centimeters. The specific gravity of the acid is found by dividing its weight by its volume, or 58.3÷55=1.06. Ans.

EXAMPLE 3.—A certain substance weighs 92 grams in air and 84 grams in water. What is its specific gravity?

SOLUTION.—The difference in weight is 92—84=8 g., which corresponds to a volume of 8 cubic centimeters. Hence, the specific gravity of the substance is 92÷8=11.5. Ans.

53. Westphal Balance.—The Westphal balance, shown in Fig. 9, is a very useful piece of apparatus for quickly and accurately determining the specific gravity of liquids. The balance consists of a beam graduated for five special weights, or riders, and from it is suspended a small glass sinker provided with a thermometer. One of the weights is used as a counterpoise to counterbalance the sinker, when immersed in water at a temperature of 60° F.

When no weights are attached to the beam, it

. FIG. 9

balances the sinker in air, but if the sinker is immersed in water the counterpoise must be placed on the first graduation in order to restore equilibrium; therefore, the counterpoise has the value 1.000. If the sinker is placed in a liquid heavier than water,
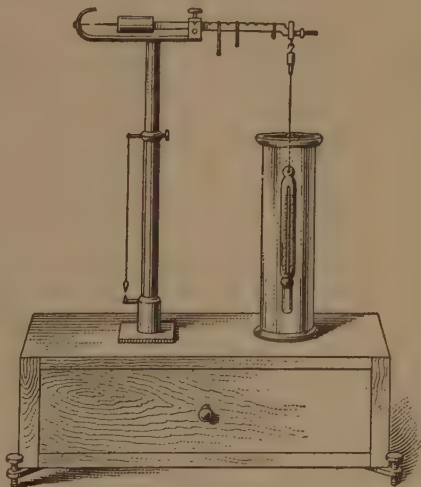
the specific gravity will be greater than 1.000 and additional weights must be added along the beam until a balance is obtained, when the specific gravity may be read off directly, beginning with the largest weight. If one of the weights is omitted in obtaining a balance, its place in the number indicating the specific gravity is represented by a cipher.

The method used in reading the specific gravity from the weights and beam may be illustrated as follows: Assume that the large weight is at the division marked 9, the next largest weight at 6, the next at 2, and the fourth at 7. Then beginning with the largest weight the specific gravity .9627 is read. If the third largest weight at the division marked 2 had been omitted in balancing the beam, the specific gravity of the liquid would be read :9607. When the specific gravity is greater than 1, the largest weight is hung from the same hook as the sinker, the remaining weights being distributed over the beam until it is balanced.

PRESSURE

AIR PRESSURES

54. Production of Low Pressures.—In connection with air and other gases it is necessary to consider the effects of pressure. Ordinary pressures are those approximately equal to atmospheric pressure, and may be called normal pressures. Those considerably greater than atmospheric pressure may be called abnormal pressures. Those below atmospheric pressure are said to be subnormal; or, in other words, they designate partial vacuums. A *perfect vacuum* is a space devoid of all matter and is practically unattainable; but a partial vacuum may be produced by the apparatus shown in Fig. 10, which is known as an *air pump,* and also as a vacuum pump. The diagram in Fig. 11 is a sectional view showing the internal arrangement of the parts of an air pump. Corresponding parts in both illustrations are indicated by the same reference letter.

55. The closed vessel *a*, Figs. 10 and 11, is called the *receiver*, and the space enclosed by it is that from which it is desired to remove the air. T h e receiver is usually made of glass, and the edges are ground so as to be perfectly airtight. When made in the form shown, it is called a *bell-jar receiver*. The receiver rests on a smooth horizontal plate, in the center of which is an opening communicating with the pump cylinder *b* by means of a
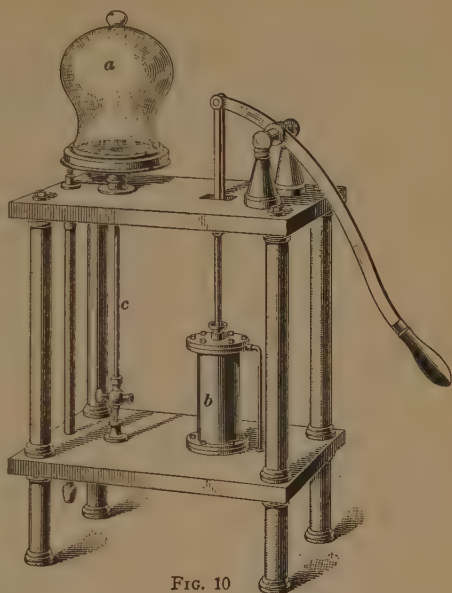
Fig. 10

tube *c*. The pump piston *d* fits the cylinder accurately, and has a valve *e* opening upwards. At the junction of the tube with the cylinder is another valve *f* also opening upwards.
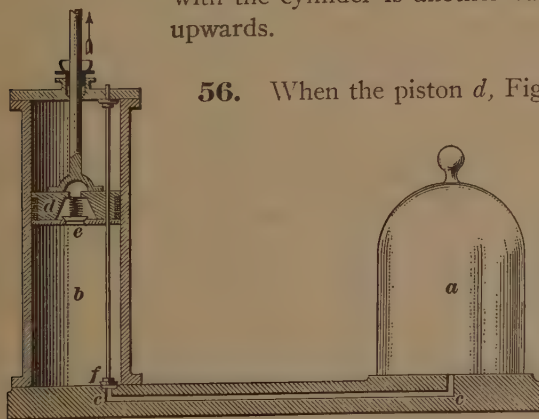
56. When the piston *d*, Fig. 11, is raised, the valve *e* closes, and, since no air can get into the cylinder f r o m above, the piston leaves a vacuum behind it. The pressure on top of the valve *f* being now removed, the pres-

Fig. 11

sure of the air in the receiver *a* causes the valve *f* to rise; the air in the receiver then expands and occupies the space displaced

by the piston, the space in the tube c, and the space in the receiver a. The piston is now pushed down, the valve f closes, the valve e opens, and the air in b escapes. The lower valve f is sometimes supported by a metal rod passing through the piston and fitting it somewhat tightly. When the piston is raised or lowered, this rod moves with it. A button near the upper end of the rod confines its motion to within very narrow limits, the piston sliding on the rod during the greater part of its travel.

**57. Weight of Air.**—That air possesses weight may be readily shown by means of an accurate and sensitive balance. If a glass bulb with a capacity of about 1 liter is balanced or weighed when filled with air, the weight will be found to be less than when the bulb is filled with air under pressure. Again, if the bulb is attached to an air pump and some of the air is removed, it will be found to have lost weight. The exact weight of 1 liter of air under certain conditions of temperature and pressure that have been accepted as standard is 1.293 grams.

58. Pressure Exerted by Air.—Since the air has weight, the enormous quantity of air that constitutes the atmosphere

Fig. 12

must exert a considerable pressure upon the earth. If one places his hand over an opening in the top of the receiver of a powerful air pump he finds that his hand is pressed downwards with great force. The total atmospheric pressure that the human body has to support amounts to several tons, but this pressure is not felt under ordinary circumstances because it is exerted equally in all directions.
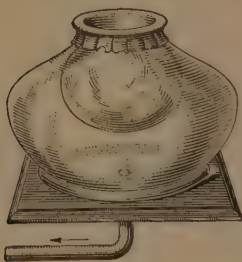
Again, if a rubber membrane is stretched over a glass vessel, as shown in Fig. 12, and the vessel is made the receiver of an air pump, the membrane will be more and more forced into the receiver, as the air is pumped out of the latter, until finally it will rupture under the pressure of the air above.

59. Measurement of Air Pressure.—The pressure due to the air may be measured without great difficulty by taking a long glass tube, closed at one end, and filling it with mercury. If the finger is placed over the open end, so as to keep the mercury from running out, and the tube is inverted and placed in a vessel of mercury, as shown in Fig. 13, the mercury will fall, then rise, and after a few oscilla- tions will come to rest at a height above the top of the mercury in the vessel equal to about 760 millimeters. This height will always be constant under similar at- mospheric conditions. Now, since the atmosphere has weight, it must press on the upper surface of the mercury in the vessel with equal intensity on every square unit, except on that part of the surface occupied by the tube. Accord- ing to Pascal's law, *the pressure per unit of area exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force upon all surfaces in a direction at right angles to those surfaces.* There- fore, the pressure of the atmosphere is transmitted in all directions. There being nothing in the tube except mercury to counterbalance the upward pressure of the air, the mercury falls in the tube until it exerts a downward pressure on the upper surface of the mercury in the ves- sel sufficiently great to counterbalance

Fig. 13

the upward pressure produced by the atmosphere. In other words, the pressure of the atmosphere now exactly balances the column of mercury which is approximately 76 centi- meters high. The weight of mercury is 13.6 grams per cubic centimeter and if the inside diameter of the tube is such that the circular area is one square centimeter, the downward pressure inside the tube is $1 \times 76 \times 13.6 = 1,033.6$ grams per
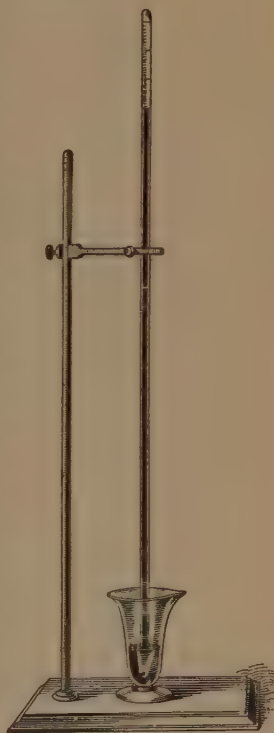
square centimeter. This pressure is equivalent to 14.7 pounds per square inch, or 1 atmosphere, and has been found to be the

average pressure of the atmosphere at sea level. When dealing with gases, normal or standard conditions of temperature and pressure are taken as 0° C. and 760 millimeters. The pressure exerted by a column of mercury 76 centimeters in height is also equivalent to the pressure exerted by a column of water 33.9 feet in height.
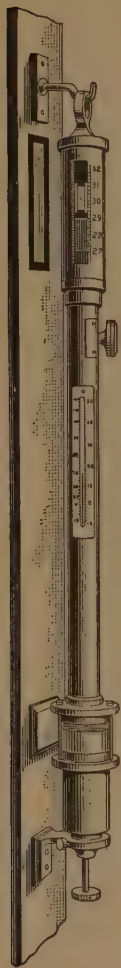
60. From the manner in which the tube shown in Fig. 13 was filled with mercury, it is evident that above the mercury in the tube a practically empty space, or vacuum, must exist. That is, this space does not contain a solid or a liquid, and only a trace of vapor or gas, and therefore it may be stated that no pressure is exerted on the upper surface of the mercury in the tube. If the top of the tube were broken off and the mercury column exposed to the pressure of the atmosphere, the column would fall and the mercury level in the tube would be the same as that of the containing vessel. It is evident, therefore, that atmospheric pressure will support a column of mercury 76 centimeters, or 760 millimeters, high only when the mercury is enclosed in a tube from the top of which the air has been removed or exhausted. If, in some manner, the pressure of the atmosphere on the mercury in the containing vessel were made less, the mercury column in the tube could not be supported at a height of 760 millimeters.

61. Barometers.—The barometer is an instrument used for measuring pressures due to the

Fig. 14

atmosphere. There are two kinds of barometers in general use, namely, the mercurial barometer and the aneroid barometer. One type of mercurial barometer is shown in Fig. 14. The principle is the same as in the case of the inverted tube shown in Fig. 13. In the barometer

shown in Fig. 14, the tube and the cup at the bottom are
protected by a brass or iron casing. At the top of the tube
is a graduated scale that can be read to $\frac{1}{1000}$ inch by means
of a vernier. Attached to the casing is an accurate thermom-
eter for determining the temperature of the outside air at the
time the barometric observation is taken. This is necessary,
since mercury expands when the temperature is increased, and
contracts when the temperature falls; for this reason a stand-
ard temperature is assumed. and all barometer readings are

Fig. 15

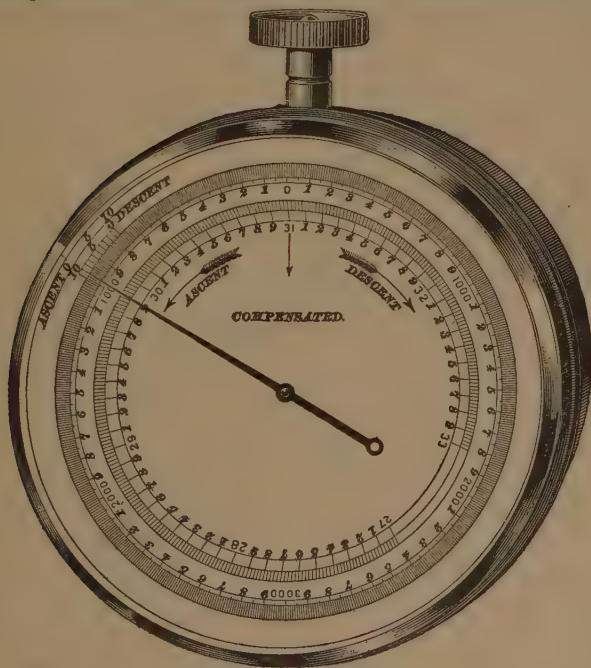reduced to this temperature, which is usually taken at 0° C.,
or 32° F., at which temperature the height of the mercurial
column is approximately 760 millimeters, or 30 inches.

62. In Fig. 15 is shown an illustration of an aneroid
barometer. The instrument is made in various sizes, from
that of a large watch up to an 8-inch or 10-inch face. It con-
sists of a cylindrical box of metal, with a top of thin, elastic,

corrugated metal. The air is removed from the box. When the atmospheric pressure increases, the top is pressed inwards, and when it is diminished, the top is pressed outwards by its own elasticity, aided by a spring beneath. These movements of the cover are transmitted and multiplied by a combination of delicate levers that act on an index hand and cause it to move to either the right or the left over a graduated scale. The barometer is self-correcting (compensated) for variations in temperature. It is portable and occupies but a small space. It must be handled with care, since it is easily damaged. The mercurial barometer is the standard.

63. Manometer.—The manometer is an instrument much used by chemists and physicists for measuring the pressures of gases in closed vessels. These pressures may be greater or less than atmospheric. The manometer illustrated in Fig. 16, consists of a bent glass tube, sealed at the upper end and fitted with a stop-cock g at the other end; this end is joined to a short tube $e f$. If the ends e and f and the stop-cock g are left open, the pressure exerted on the surface of the mercury in the limb k is that of the atmosphere. The space above the mercury in the limb j is empty and therefore represents a vacuum. If a vacuum pump is attached to the end f, after the end e has been closed, the distance between the two levels of the mercury column, which is normally equal to 760 millimeters, will gradually decrease and the ends may shortly occupy the positions indicated by the lines $a b$ and $c d$. This position may, for instance, correspond to a pressure of 600 millimeters, and a partial vacuum exists in the limb k. As the operation of the vacuum pump is continued, the levels of the mercury columns in the two limbs j and k tend to approach each other as zero pressure is reached.
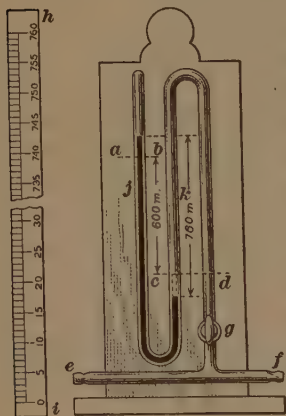
FIG. 16

64. In commercial manometers, a scale graduated in millimeters similar to that shown at *h i*, Fig. 16, is employed. The scale moves in a vertical direction and may be adjusted so that the zero point is on the same level as that of the lower level of the mercury column, thus allowing the distance between the mercury levels in the two limbs to be read off directly on the scale. In laboratory work the end *e* of the manometer is connected to the vessel or apparatus in which a given reduction of pressure is to be produced, the manometer indicating when the desired pressure has been reached. That is, the distance between the two levels of the mercury column as read from the scale is a measure of the pressure in the vessel.

65. Effect of Pressure on Volumes of Gases.—The effect of pressure on the volumes of gases was investigated by Robert Boyle, who, in the year 1661, found that if the temperature of a gas is kept constant, a given volume will vary inversely as the pressure put upon it. In other words, the volume of a gas decreases as the pressure upon it increases and increases as the pressure is decreased. This relation of the volume of a gas to the pressure to which it is subjected is known as Boyle's law and the truth of it may be easily demon-

FIG. 17

strated by use of the apparatus illustrated in Fig. 17. It consists of a glass **U** tube mounted on a wooden stand. The limb *a* of the tube is sealed and the upper end of the limb *b* is open to the air. If a quantity of mercury is poured into the open end so as to fill the **U** tube completely and then the tube is tilted, if necessary to allow some of the air to escape from the short limb, the levels of the mercury in the two limbs are made equal. The pressure on the mercury in the limb *b* will then be the same
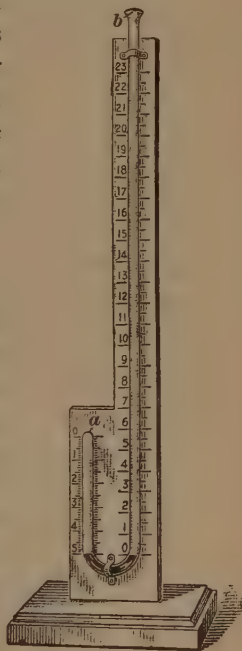
as that of the atmosphere and, therefore, the pressure on the
confined air in the closed limb *a* will be 1 atmosphere.   If an
additional quantity of mercury is then introduced into the
limb *b*, the volume of air above the mercury in the limb *a* will
become smaller.   If the tube were at least 30 inches in height,
it could be shown that the volume of air in the limb *a* is reduced
just one-half by filling the limb *b* with mercury to a height of
about 30 inches, or 760 millimeters.   With this quantity of
mercury in the limb *b*, the pressure exerted on the air in the
limb *a* is equivalent to 2 atmospheres, and with apparatus
sufficiently large and strong, it can be shown that, given a cer-
tain volume of a gas, this volume can be made to decrease
according to the increase in pressure.   Thus, a volume of 1
liter is decreased to $\frac{1}{2}$ liter by a pressure of 2 atmospheres;
to $\frac{1}{3}$ liter by a pressure of 3 atmospheres, and so on.

MOVING LIQUIDS BY PRESSURE

66.   Siphon.—The siphon is often used by chemists and
engineers either to empty vessels that are too large to be over-
turned or to remove the liquid from a vessel without disturbing
a sediment that may be deposited on its bottom.   In its
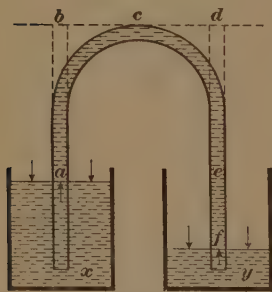
simplest form the siphon consists of
an inverted **U**-tube as shown in Fig. 18.
The vessels *x* and *y* may be at the same
or different levels, and it is assumed
that the water contained in the ves-
sel *x* is to be transferred to the
vessel *y*.   The siphon *a c f* is first
filled with water, as shown.   It is ob-
vious that water will pass through it
if the forces acting in one direction are
greater or less than those acting in the
opposite direction.   The forces that must be dealt with in this
case are those due to the pressure of the atmosphere on the sur-
faces of the water in the vessels *x* and *y*, and also those due to
the weights of the water columns in the limbs *a c* and *f ε c*
of the siphon.

67. The pressure due to the air is the same for each square inch on both water surfaces in the vessels x and y, Fig. 18; therefore, the upward pressure at a is equivalent to the pressure of the air minus the downward pressure due to the water column $a\,c$, while the upward pressure at f is equivalent to the air pressure minus the downward pressure due to the water column $f\,e\,c$. The latter column is longer and consequently heavier than the column $a\,c$ by the weight of the section $e\,f$. Thus, the upward pressure at f is less than that at a, the difference amounting to the weight of that section of the column between e and f, and the water will therefore flow from the vessel x into the vessel y until the levels of the water in both vessels are the same and the water columns in the limbs $a\,c$ and $f\,e\,c$ are of equal lengths. In order that all of the water be transferred it is necessary that the vessel y be located at such a distance below the vessel x that, when the vessel is full, the level of the liquid in it will be at the same or at a lower level than the bottom of the vessel x. Liquids cannot be transferred from a lower to a higher level by the siphon.

68. Suction Pump.—The simple suction pump illustrated in Fig. 19 consists of a steel cylinder a that contains a tightly fitting piston b with valves c that open upwards. The bottom of the cylinder is fitted with a pipe d that leads to the water supply, and just over the entrance of this pipe to the cylinder is located the valve e, which also opens upwards. When the piston of the pump is drawn upwards, a partial vacuum is created below it and the pressure of the atmosphere forces water up through the pipe d and the valve e, the valves c remaining closed. When the piston reaches the upper end of its stroke, and begins to descend, the valve e closes and prevents the escape of the water while the valves c open and thus allow the water to pass above the piston. On the next upward stroke of the piston, the water above it is lifted mechanically and passes out of the cylinder through the opening f.

If ordinary air pressure will support a column of water only 33.9 feet in height, the piston of the pump must not be

at a greater distance than this above the level of the water that is to be pumped. In practical work, however, an absolute vacuum is never realized and therefore it is impossible to raise water to a greater height than about 32 feet by means of the simple suction pump.

69. Force Pump.—The simple force pump illustrated in Fig. 20 consists of a cylinder a that contains a solid piston b.
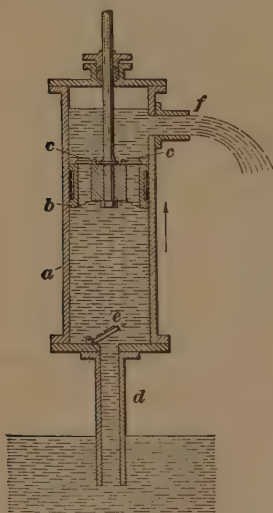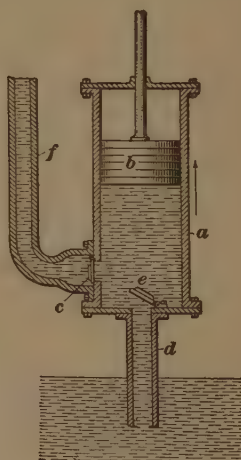
<center>Fɪɢ. 19   Fɪɢ. 20</center>

The discharge valve c opens outwards while the valve e over the intake pipe d opens into the cylinder. The action of the force pump is similar to that of the suction pump. When the piston is raised, water flows into the cylinder through the pipe d and the valve e, and when the piston descends the water in the cylinder is prevented from escaping through the pipe d by the valve e and is therefore forced out through the valve c and the discharge pipe f.

HEAT

MEASUREMENT OF LOW TEMPERATURES

70. Heat is a form of energy and can be produced by the expenditure of mechanical energy; for instance, if a hole is drilled in a piece of steel, both the drill and the steel become hot; or, if an automobile tire is pumped up, the pump becomes heated. Under ordinary circumstances, temperatures are measured by mercury and alcohol thermometers; but in scientific work it is frequently necessary to measure temperatures that are much lower than the freezing point of mercury, or of alcohol, which is also used in thermometers designed for low temperature work. Mercury freezes at −38.8° C., and alcohol at −114° C.; therefore, temperatures below these points cannot be measured by the use of the mercury or the alcohol thermometer. In such cases, the *hydrogen thermometer,* illustrated in Fig. 21, may be used. The bulb *a* is filled with hydrogen gas. The tube *b* contains mercury, represented by the black column, and is connected to the bulb *a* by a flexible tube *c* that permits either part of the thermometer to be raised or lowered. The space above the mercury in tube *b* is exhausted as completely as possible. The bulb *a* is surrounded by melting ice, and after it has been given time to cool to the temperature of the ice water, the tube *b* is raised until the level of the mercury in the tube *d* exactly coincides with a mark on the tube at *e*. Now, since the space above the mercury column at *f* has been exhausted, the pressure exerted by the hydrogen in the bulb *a* against the mercury surface at *e* just supports the mercury column *f g*.
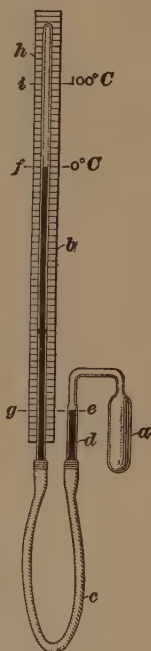
FIG. 21

The point f is now marked on the strip h, which is fastened to the tube b.

71. The bulb a, Fig. 21, is next placed in a steam bath, which causes the hydrogen gas in it to expand and force the mercury level below e in the tube d and above f in the tube b; but, by raising the tube b, the mercury level in the tube d is again brought back to the point e. The increased pressure due to the hydrogen in the bulb a is now balanced by the increased height of the mercury column in the tube b, the upper level of which is now at the point i. This position is also marked on the strip h. The points f and i are then marked 0° C. and 100° C., respectively, since they were located by first immersing the bulb a in melting ice and then in steam at atmospheric pressure. The vertical distance between the points f and i is divided into 100 equal parts, and divisions of exactly the same length are carried above the 100° C. mark and below the 0° C. mark, as shown. Each mark then represents 1° C. change in temperature.

To use the hydrogen thermometer, the bulb a is immersed in the substance the temperature of which is desired, and the tube b is adjusted until the mercury level in the tube d stands again at the point e. The reading is taken at the mercury level in the tube b. If this reading, for example, is 180 divisions below the point f, or 0° C., as it would be if the bulb a were immersed in liquid air, the temperature indicated would be − 180° C.

EXPANSION OF SOLIDS

72. Introductory.—The volume of any body—solid, liquid, or gaseous—is always changed if the temperature is changed; nearly all bodies expand when heated, and contract when cooled. In solids having definite shapes, the expansion may be considered in three ways, according to the conditions.

1. Linear expansion, or expansion in one direction, as the elongation of an iron bar.

2. Surface expansion, where the area is increased.

3. Cubical expansion, where the increase in the whole volume is considered.

73. Linear Expansion.—An apparatus for exhibiting the linear expansion of a solid body is shown in Fig. 22. A metal rod *A* is fixed at one end by a screw *B*, the other end passing freely through the eye *C*, held in the post, and pressing against the short arm of the indicator *F*. The rod is heated, as shown, and its elongation causes the indicator to move along the arc *D E*.

74. Surface Expansion.—An illustration of surface expansion is afforded every day in locomotive shops, where piston rods, crankpins, etc. are shrunk in, and tires are shrunk on their centers. In shrinking a tire on, it is bored a little

FIG. 22

smaller than the wheel center. The tire is then heated until it expands enough to allow it to slide over the wheel center. On being cooled with water, the tire contracts, and tends to regain its original area, but cannot because the wheel center is a trifle larger. This causes the tire to hug the center with immense force, and prevents it from coming off.

75. Cubical Expansion.—Cubical expansion may be illustrated by means of a *Gravesandes's ring*. This consists of a brass ball *a*, Fig. 23, which at ordinary temperatures passes freely through the ring *m*, of very nearly the same diameter. When the ball is heated it expands so much that it will no longer pass through the ring.

76. Examples of Expansion and Contraction.—If sufficient consideration is not given to the expansion or contraction of substances under changes of temperature, disastrous results

are liable to occur, especially in engineering and construction work. In the physical laboratory, all measurements must either be carried out at the same temperature when conducting an experiment or allowance must be made for variations in temperature. It is a well-known fact that in laying the rails on railroads, a small space is left between adjacent rails; for, if they touched, the force set up by expansion on a hot day would
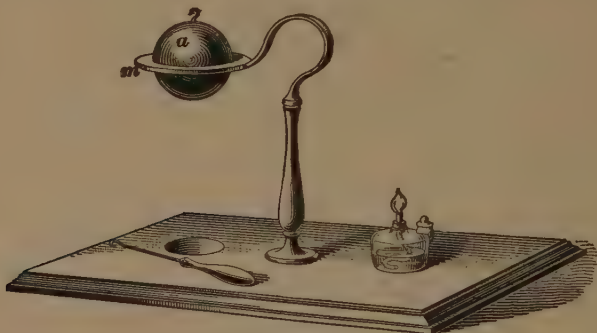
Fig. 23

cause them to curve. Hot-water pipes are fitted to one another by means of telescope joints, which allow room for expansion; so, also, are steam pipes, by means of so-called expansion joints. If an ordinary glass vessel is heated or cooled too rapidly, it cracks, especially if it is thick; the reason for this is that since glass is a poor conductor of heat, the sides become unequally heated, and, consequently, unequally expanded, which causes a fracture. The grate bars of a furnace must not be fitted tightly, but must be free at one end; otherwise, in expanding, they will split the masonry.

EXPANSION OF LIQUIDS

77. Finding Coefficient of Expansion.—The expansion of liquids is peculiar in that it is not constant for different temperature ranges. Therefore the rate at which any given liquid expands depends on the temperature range through which it is taken.

The extent to which liquids expand, per unit volume, for each degree rise in temperature—or, in other words, the coefficient of expansion—can be easily and accurately measured by means of the simple apparatus illustrated in Fig. 24. The apparatus is constructed of glass and consists of a bulb a of known volume connected to a funnel b by a graduated capillary tube c. If it is desired to obtain the coefficient of expansion of water, the bulb a is filled with water up to the mark d and then heated until the water level appears at some point, as e, for instance. The expansion in cubic centimeters is then read from the tube and the coefficient of expansion is calculated. Thus, suppose that the bulb contains 100 cubic centimeters of water when filled up to the mark d, at 0° C., and that the water expands until its level reaches the mark e when it has been heated to 100° C. If the difference in the two readings is 5 cubic centimeters, the calculations are made as follows:

FIG. 24

$$
\begin{aligned}
\text{Volume at } 0°\text{ C.} \quad &= 100 \text{ c. c.} \\
\text{Volume at } 100°\text{ C.} \quad &= 105 \text{ c. c.} \\
\hline
\text{Expansion} \quad &= \quad 5 \text{ c. c.} \\
\text{Expansion per c. c.} &= 5 \div 100 = .05 \text{ c. c.}
\end{aligned}
$$
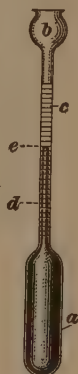
Expansion of unit volume per degree Centigrade = $.05 \div 100$ = .0005 c. c. or .0005 of the unit of volume. Therefore, the coefficient of expansion is .0005, since it is always expressed as an abstract number. To obtain accurate results by this method, the coefficient of expansion of the glass of the bulb must be known and the necessary correction must be made.

78. Maximum Density of Water.—When water is cooled from its boiling point, it continually contracts until it reaches a temperature of 4° C.; then it begins to expand until 0° C. is reached, at which point it freezes. On the other hand, if water at 0° C. is heated, it contracts until 4° C. is reached, and above this point it begins to expand. The maximum density of water is therefore at 4° C., as can be shown by a simple experiment performed with the aid of the apparatus illustrated in Fig. 25. It consists of a tall glass cylinder a, pro-

vided with two thermometer openings *b*. The thermometers are inserted as shown, and the cylinder is filled with water at any convenient temperature, say 20° C., and then surrounded with ice contained in the vessel *c*. On observing the temperatures indicated by the thermometers it will be seen that the lower one falls much more rapidly than the upper one until a temperature of 4° C. is reached. At this point it becomes stationary. This observation indicates that water at 4° C. is
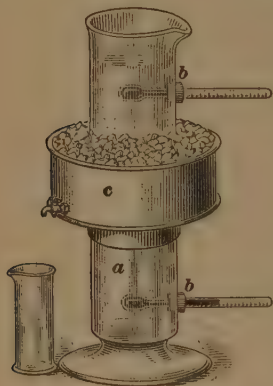
heavier, or of greater density, than water at the higher temperature indicated by the upper thermometer. If this were not true the colder water would not sink to the position of the lower thermometer. With the lower thermometer registering 4° C., it will be noticed that the upper one has begun to fall and also that it does not become stationary at 4° C., but continues to fall until it registers 0° C. This would seem to indicate that water at 0° C. is lighter than is water at 4° C.; for, since the cooling is being

FIG. 25

done at the middle point of the cylinder, the only way in which the upper thermometer could be made to indicate 0° C. is by the rising to the surface of the lighter water which has been cooled below 4° C.

79. Cooling of Natural Bodies of Water.—The results obtained on carrying out the foregoing experiment explain the cooling and subsequent freezing of any body of water during cold weather. The water at the surface becomes cold, and being heavier than the warmer water beneath it, it sinks. The process is continued until the entire body of water is at a temperature of 4° C.; then further cooling at the surface makes the water at this point of less density than the water beneath at 4° C. Therefore, the colder water remains at the top and freezes. This explains why a lake begins to freeze at the surface and not from the bottom up.

EXPANSION OF GASES

80. It has already been shown that when the pressure on any given volume of a gas is increased, the volume decreases. When heat is applied to a gas, however, and the pressure to which it is subjected is kept constant, it will be found to occupy a greater volume at the higher temperature. In other words, the gas expands, and the extent of this expansion has been accurately measured and found to be $\frac{1}{273}$ of its volume at 0° C. for each degree rise in temperature. Thus, if one liter of a gas at 0° C. is heated to 1° C., and the pressure on it adjusted, the volume will be found to be $1\frac{1}{273}$ liters. The decimal equivalent of $\frac{1}{273}$ is .00366, and represents the coefficient of expansion of any gas.

HEAT TRANSFER AND MEASUREMENT

81. Conduction of Heat.—Conduction is the transfer of vibratory motion from molecule to molecule in the *same* body. Different bodies possess very different conducting powers, the good conductors being those in which conduction is most rapid,

TABLE I
RELATIVE HEAT CONDUCTIVITIES OF METALS

Metal	Relative Conductivity	Metal	Relative Conductivity
Silver	100.0	Iron................	11.9
Copper	73.6	Steel...............	11.6
Gold	53.2	Lead...............	8.5
Brass	23.1	Platinum...........	8.4
Zinc	19.0	Rose's alloy........	2.8
Tin	14.5	Bismuth............	1.8

and the poor conductors those in which it is very slow. Experiments have established a numerical comparison of the conducting powers of many bodies. Representing the conducting power of silver by 100, Table I shows the conducting

powers of a number of other metals as determined by Weidemann and Franz.

82. As a class, the metals are the best conductors; the fluids, both liquid and gaseous, are very poor conductors, their conducting power being hardly appreciable. Water, for example, can be made to boil at the top of a vessel, while a cake of ice is fastened within a few inches of the surface. If thermometers are placed at different depths, *while water boils at the top,* it is found that the conduction of heat downwards is very slight.

Organic substances conduct heat poorly. This enables trees to withstand great and sudden changes in the atmosphere without injury. The bark is a poorer conductor than the wood beneath it. Cotton, wool, straw, bran, etc. are poor conductors. Rocks and earth are poorer conductors, the less dense and homogeneous the mass; hence, the length of time required for the sun's rays to penetrate the earth.

83. Measurement of Heat.—Temperature is not a measure of quantity of heat, for a thermometer will indicate the same temperature both in a vessel containing one liter, and in one containing ten liters, of boiling water, although it is evident that the one must contain ten times as much heat as the other; again, to raise ten liters of water to the boiling point requires ten times the amount of heat necessary to raise one liter to the boiling point. *Quantity of heat is measured by the amount necessary to raise a certain weight of some body from one temperature to another temperature.* Three common units, in terms of which heat is measured, will be defined.

1. The **British thermal unit,** which represents the amount of heat required *to raise 1 pound of water 1° Fahrenheit.* The words "British thermal unit" are abbreviated to B. t. u. Thus, 7 pounds of water raised 15° F. would require 7×15 $= 105$ B. t. u.

2. The **Calorie** (Cal.), which represents the amount of heat necessary *to raise 1 kilogram of water 1° centigrade.* It is sometimes called the *great calorie,* or *kilogram calorie,*

to distinguish it from the small, or gram, calorie. One kilogram = 2.2 pounds and 1° C. = $\frac{9}{5} \times 1$° F.; hence, a great calorie = $2.2 \times \frac{9}{5} = 3.96$ B. t. u.

3. The **calorie** (cal.), which represents the amount of heat necessary *to raise 1 gram of water 1° centigrade*. This is called the *small calorie,* and its value is $\frac{1}{1000}$ of the great calorie.

SPECIFIC HEAT AND LATENT HEAT

84. Specific Heat.—When equal weights of two different substances having the same temperature are placed in similar vessels and subjected for the same length of time to the heat from the same source, it is found that their final temperatures will differ considerably; thus, mercury will be much hotter than water. As, from the conditions of the experiment, each has been receiving the same amount of heat, it is clear that the quantity of heat sufficient to raise the temperature of mercury through a certain number of degrees will raise the same weight of water through a smaller number of degrees; in other words, it requires more heat to raise a certain weight of water 1° than it does to raise the same weight of mercury 1°. Conversely, if the same quantities of water and of mercury at 200° are allowed to cool down to the temperature of the room, the water will require a much longer time than the mercury; hence, in cooling through the same number of degrees, water gives up more heat than mercury.

85. The number of heat units or parts of a heat unit required to raise the temperature of a unit quantity of any substance 1° is called the *specific heat* of that substance. It will be seen from this definition, that the specific heat of a substance is the ratio between the amount of heat required to raise the temperature of the substance 1° and the amount of heat required to raise the temperature of the same weight of water 1°.

If the specific heat of lead were given as .0314, it would mean that the amount of heat required to raise a certain weight of lead 1° would raise the same weight of water only

.0314°; or it would mean that .0314 B. t. u. would raise the temperature of 1 pound of lead 1° F.

EXAMPLE.—The specific heat of copper is .0951. How many B. t. u. will it take to raise the temperature of 75 pounds 180° F.?

SOLUTION.—Since it takes .0951 B. t. u. to raise 1 pound of copper 1°, it will take .0951×75×180 to raise 75 pounds 180°. Hence,

$$.0951 \times 75 \times 180 = 1,283.85 \text{ B. t. u. Ans.}$$

In the example just given, if it had been required to raise 75 pounds of water 180° (that is, from the freezing point to the boiling point), it would have taken $75 \times 180 = 13,500$ B. t. u.; but $\frac{1,283.85}{13,500} = .0951$, the specific heat of copper.

86. Heat of Fusion.—If a quantity of cracked ice is put in a vessel held over a flame, heat passes rapidly into the ice and melts it. A thermometer resting in the mixture of ice and water shows no tendency to rise, but remains at 0° C. until all of the ice has been melted. Where has the heat gone that was supplied to the ice? This question may be answered by assuming that the heat energy that has apparently disappeared has been used up in tearing apart the molecules that make up the ice, thus converting it to the liquid state in which the molecules are less closely held together. This energy is commonly called *latent heat of fusion*. The numerical value of the latent heat of fusion of ice may be accurately determined. Thus, when a quantity of ice, say 415.3 grams, is placed in 2,500 grams of water at 60° C., it is found, after the ice has melted, that the temperature of the water has been lowered to 40° C. The number of calories furnished by the water is

$$2,500 \times (60 - 40) = 50,000 \text{ calories}$$

The ice water formed by the melting ice was raised in temperature from 0° C. to 40° C., which required

$$415.3 \times (40 - 0) = 16,612 \text{ calories}$$

The remainder of the heat, or $50,000 - 16,612 = 33,388$ calories, must have been used in melting the 415.3 grams of ice. Then, the number of calories required to melt 1 gram of ice is

$$33,388 \div 415.3 = 80.3 \text{ calories}$$

Very accurate determinations of this constant have made it an even 80 calories.

87. Evaporation.—It is well known that when a vessel containing water is left uncovered and the water is thus exposed to the air, it will steadily diminish in volume due to evaporation. In order to explain satisfactorily the phenomenon of evaporation it is assumed that, as in the case of a gas, the molecules of a liquid are in constant motion; since, if they were not in motion, they could not escape from the liquid. Concerning the constantly moving molecules, it is plausible to assume that, due to their collisions, some of them are moving faster than others, and when any one molecule attains a speed great enough to enable it to overcome the attractive force exerted on it by other molecules, it escapes from the liquid. An increase in the temperature of a liquid causes an increase in the velocities of its molecules and more of them escape from the liquid. Thus, evaporation proceeds more rapidly at high temperatures than at low temperatures.

88. Temperatures of Solution.—When some substances are dissolved in water the temperature of the solution becomes lower than that of the water; and, in some cases, the solution of substances causes a rise in temperature. Thus, when sodium chloride (salt) or ammonium nitrate is dissolved in water the temperature of the resulting solution is lowered; but when sulphuric acid or caustic soda is dissolved, a rapid rise in the temperature of the solution is noted. These phenomena may be explained by considering the movements of the molecules. When salt is placed in water, the molecules at the surfaces of the salt crystals tend to escape from these surfaces due to their own velocities and because of the attraction of the water molecules. When any certain molecule escapes from the surface of a salt crystal it is under the influence of two opposing forces; one, the attraction of the water molecules, tends to increase its velocity, while the other, the attraction of the remaining molecules of the salt crystals, tends to diminish its velocity. If, then, the attraction of the water molecules for the salt molecules is less for the

escaping molecules than is the attraction of the remaining salt molecules, the velocities of the escaping salt molecules will be lessened and the solution will be cooled, whereas, when the attraction of the water molecules exerts the greater force, the velocities of the escaping molecules will be increased and the temperature of the solution will likewise be increased, as is the case when sulphuric acid is dissolved in water.

89. Freezing of Solutions.—Water solutions of most substances freeze at lower temperatures than does pure water. When ordinary salt is dissolved in water, the solution will not freeze at 0° C., but at several degrees below this temperature. This may be explained by considering what happens when water is cooled. When the temperature of water is reduced, the velocities of its molecules are also reduced, and the forces between the molecules can make themselves felt. Thus the molecules of water are pulled so closely together that they assume the crystalline form.

TABLE II
FREEZING MIXTURES

Substance	Parts by Weight Used	Substance	Parts by Weight Used	Temperature Attained by Mixture Degrees C.
Ammonium carbonate....	30	Water	100	3.2
Ammonium nitrate.......	100	Water	94	−4.0
Ammonium chloride......	30	Water	100	−5.1
Sodium nitrate	75	Water	100	−5.3
Ammonium chloride......	25	Ice	100	−15.4
Sodium nitrate..........	50	Ice	100	−17.75
Sodium chloride.........	33	Ice	100	−21.3
Sulphuric acid (66.0 per cent.).................	100	Ice	110	−37.0
Calcium chloride........	100	Ice	70	−50.0

Thus, it is seen that a temperature of −21.3° C. is attained by the use of a mixture consisting of 33 parts of sodium chloride (salt) and 100 parts of ice.

However, in the case of a solution, the attractive forces between the liquid molecules are partly counterbalanced by the attractive forces existing between the molecules of the salt and the water, and in order to cause the solution to freeze, the velocities of the molecules of the liquid must be further reduced. This is done by further cooling, whereupon the solution freezes.

90. Freezing Mixtures.—It has been shown how and why solutions of different substances in water freeze at a lower temperature than does water, and the principle involved is frequently made use of by the chemist and physicist. Ice melts at 0° C., and when enough of it is placed in a vessel containing water, the latter melts the ice. In doing so its temperature is reduced to 0° C., which is the freezing point of pure water. Likewise, if ice is placed in salt water, the latter will not freeze until its temperature is reduced to the freezing point of the solution. Solutions of this type, which freeze at temperatures below 0° C., are called freezing mixtures, and reductions of temperature over a wide range may be obtained by their use. Table II indicates the efficiency of different freezing mixtures.

PHYSICS
(PART 2)

LIGHT AND ELECTRICITY

LIGHT AND ITS ACTION

VELOCITY AND INTENSITY

1. Velocity of Light.—The ordinary observer will conclude that the transmission of light from its source to any other point is instantaneous and ordinary measurements will not show this conclusion to be erroneous. Galileo, who in 1609 invented the simple telescope that bears his name, concluded as the result of an experiment which consisted in flashing lights from one hill-top to another, that the passage of light from one point to another was instantaneous.

2. That time was actually required for light to pass through space was shown to be the case, in 1676, by Roemer, a Danish astronomer. Roemer, in observing the eclipses of one of the moons of the planet Jupiter, noted that the actual time of eclipse of this moon differed from the computed and predicted time. The reason for this observed discrepancy is made plain in Fig. 1. Each time that Jupiter's moon a passes around the planet b it passes into the shadow c of the planet; in other words, an eclipse of this moon occurs. Roemer determined the time elapsing between two consecutive eclipses when the earth was at the position d and found it to be 42 hours, 28 minutes, and 36 seconds. Possessing this informa-

tion, he could predict just when an eclipse should occur six months later, when the earth had reached a point d' in its path around the sun e, exactly opposite the point d, and again twelve months later when the earth had again reached d. However, when the eclipse was observed with the earth at d', it was found to occur 16 minutes and 36 seconds later than the predicted time, while again at the end of the twelve-month period it took place at the predicted time.

3. Because of his observations, Roemer believed that a period of 16 minutes and 36 seconds, or 996 seconds, was required for light to travel across the earth's orbit, a distance calculated to be about 191,381,960 miles. The velocity of light arrived at by these figures was $\dfrac{191,381,960}{996} = 192,150$ miles per second. Within comparatively recent years, however, the velocity of light has been measured by other investigators who used different methods, and, as a result of their measurements, the speed of light is now taken as 186,000 miles per second. The velocity of light varies with the medium through which it passes. Its velocity through an empty space, or
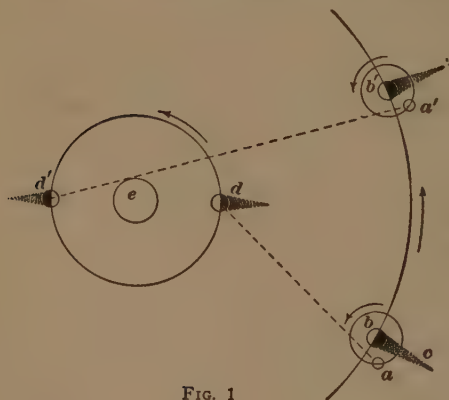
Fig. 1.

vacuum, is practically the same as its velocity through air; but in passing through liquids or solids the velocity changes, as will be shown.

4. Propagation of Light.—That light travels in straight lines is evident to anyone who has observed the rays of a searchlight sweeping the skies at night or the passage of a ray of light through a darkened dust-filled room. Again, when the source of light is cut off by any opaque object, the latter

casts a sharp and well-defined shadow, indicating that light
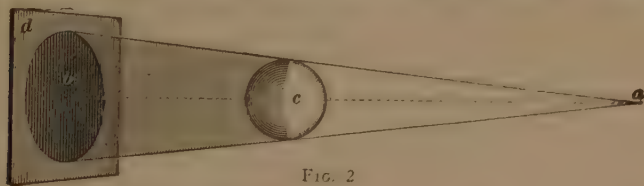does not curve around the edges of the object.   When an

Fig. 2

opaque object is placed between a source of light and a suitable
background, a shadow is cast by the object, and the character
of the shadow depends on the source of light.   Thus, when
the source of light is a point *a*, as shown in Fig. 2, the shadow *b*
cast by the object *c* on the screen *d* will be uniformly dark.
This shadow is called the *umbra*.   When the source of light is
larger than a mere point, however, two shadows *b* and *e* are
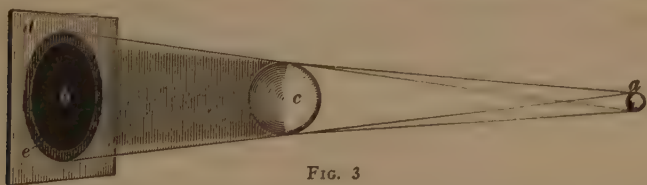
Fig. 3

formed, as shown in Fig. 3.   The larger and lighter shadow *e*
is called the *penumbra*.   When the source of light is much
larger than the object, the umbra becomes a cone in shape.
An eclipse of the moon is illustrated in Fig. 4.   Here the
moon is shown in the cone-shaped shadow cast by the earth.

5.   Intensity of Light.—It is a matter of common knowledge
that a light appears to lose its brilliancy or intensity as the
distance between it and the observer increases.   The varia-
bility of the intensity
of light can be de-
monstrated by a
simple experiment
and the law governing

Fig. 4

it can be deduced by the use of the simple photometer illus-
trated in Fig. 5.   Referring to the illustration, *a* represents a

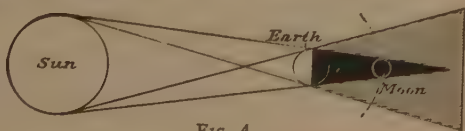screen, *b* an opaque object, and *c* and *d* candles of the same size. The apparatus is placed in a dark room and the candles are lighted. The group of four candles at *d* is placed in such a position that a shadow of the object *b* is cast on the screen *a*. The single candle *c* is next placed in such a position that it will also cast a shadow on the screen beside the one cast by the four candles.

6. From the positions of the candles in Fig. 5, it may be seen that light from each source is cast on the shadow due to the other source of light. In other words, light from the candles *d* will illuminate the shadow due to the candle *c*, and light from the candle *c* will illuminate the shadow due to the candles *d*. Therefore, the two shadows will appear equally dark only when the light received at the screen from both sources is of the same intensity. To render the two shadows equally dark, the group *d* or the
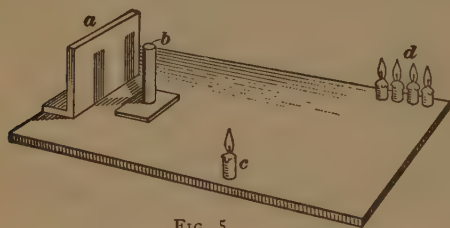
Fig. 5

candle *c*, or both, must be moved closer or farther from the opaque object *b*.

7. When the candles at *c* and *d*, Fig. 5, have been moved so as to make the two shadows equally dark, the distances between *a* and *c* and *a* and *d* are measured. The distance from *a* to *c* will be found to be one-half the distance from *a* to *d*. As there are four candles at *d*, each of them produces an illuminating effect only one-fourth as great as the candle *c*, when the latter is at one-half their distance from the screen. The intensity of light therefore varies inversely as the square of the distance from the source. If the candle *c* were moved to the position *d* and the four candles at that point were removed or extinguished, the illumination at *a* would only be one-fourth as great as when the candle is at *c*. In other words, by doubling the distance of the candle *c* from the screen, the illuminating effect at the screen becomes only one-fourth

as great; if the distance were trebled, the illuminating effect would be one-ninth as great; and so on.

8. **Measurement of Candlepower.**—If the distance from a to c, Fig. 5, is one foot and that from a to d is two feet, a single source of light, such as a gas flame, placed at d would possess an illuminating power equal to that of four candles if the illuminating effect on the screen were the same as when the four candles occupied the position of the gas flame. As the distances are in the ratio of 1 to 2 and the illuminating effects are in the ratio of 1 to 4, it is evident that the candle-powers of any two sources of light that produce equal illuminating effects on a screen are directly proportional to the squares
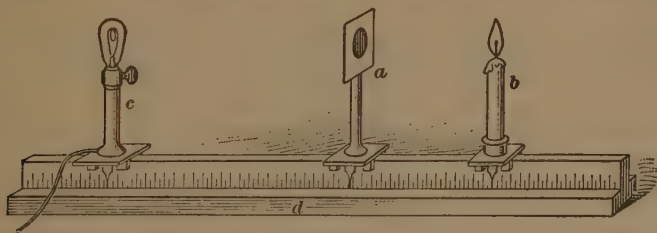
Fig. 6

of the distances of the light sources from the screen; for $1 : 4 = 1 : 2^2$. The illuminating effect, or candlepower, of a source of light may be found by a photometer.

9. The Bunsen photometer consists essentially of a paper screen a, Fig. 6, suitably mounted on a graduated base d along which it may be moved, and having a small circular oiled spot in its center. When the screen is placed between two sources of light of unequal intensity, both sides are of course illuminated, but unequally. On that side which is the more strongly illuminated the oiled spot appears dark, while on the side least illuminated, the oiled spot appears bright.   If the screen is moved back and forth until it reaches a position at which it is equally illuminated on both sides, the oiled spot is no longer visible.

10. To use the Bunsen photometer, a candle b, Fig. 6, or any other source of light, the candlepower of which is

known, is placed on one side of the screen. The lamp c, the candlepower of which is to be found, is placed on the other side. The screen is adjusted until the illumination on both sides is the same and the distance from each source of light to the screen is then read from the scale. From the data thus obtained the candlepower of the lamp can be calculated by the proportion $x : c = m^2 : n^2$, in which x is the candlepower of the lamp, c the candlepower of the candle, and m and n the distances of the lamp and the candle, respectively, from the screen. For example, suppose that a candle of 1 candlepower, placed 50 centimeters from the screen, gives the same illumination as a lamp placed 200 centimeters from the screen. The candlepower of the lamp is then found by using the foregoing proportion, making $c = 1$, $m = 200$, and $n = 50$; thus, $x : 1 = 200^2 : 50^2$, or $x = 200^2 \div 50^2 = 16$, the candlepower of the lamp.

11. Definition of Candlepower.—A candlepower may be defined as the illuminating power of the light emitted by a sperm candle $\frac{7}{8}$ inch in diameter burning at the rate of 120 grains of wax per hour. This candle is still used in some laboratories for certain routine work, but accurate results are difficult to obtain by its use. The intensity of a source of light that possesses the equivalent of one candlepower is established by standard incandescent lamps maintained by the Bureau of Standards, Washington, D. C. This standard has been accepted by Great Britain and France and is called the *international candle*. Another standard that is gradually coming into use is the pentane lamp, which burns a mixture of pentane vapor and air.

REFLECTION AND REFRACTION OF LIGHT

12. Angle of Incidence and Reflection.—Light that comes through a small opening constitutes what is known as a beam of light. When the opening is very narrow, however, as in the case of a mere slit, the light that comes through is known as a ray. When a ray of sunlight enters a darkened room, its path is rendered visible by the reflection of light from

the particles of dust that float in the air of the room. If a mirror is placed in the path of the ray, its direction will be changed, as shown in Fig. 7. The ray enters the room at a, strikes the mirror at b, and passes upwards along the line bc. The ray ab is called the incident ray and bc the reflected ray. If the line bz is drawn at right angles to the mirror at the point b—that is, perpendicular to the mirror at the point b —the angle x equals the angle y. As x represents the angle of incidence and y the angle of reflection, it follows that the angle of incidence and the angle of reflection are equal.

13. Diffusion of Light.—A very smooth surface, such as that of a mirror, reflects light almost perfectly. A surface that is slightly rough, however, such as that offered by a sheet of white paper of good quality, does not reflect light in the same man- ner as does a mirror. Thus, when a ray of light enters a darkened room and is reflected from a mirror, the course of the reflected ray is plainly visible. When the reflecting
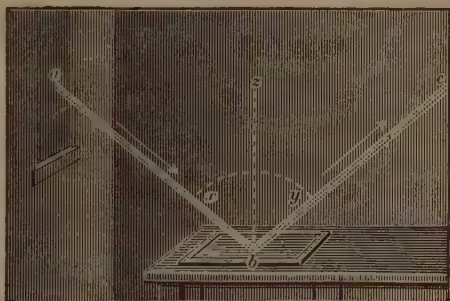
Fig. 7

surface is a sheet of paper, a reflected ray cannot be seen, but the whole room will become much brighter, because the rough or unpolished surface of the paper causes the light to be reflected in all directions, or diffused. A ray of light entering a darkened room would not be visible if the room were perfectly free from dust; but the dust particles in its path act as small reflectors.

14. Refraction of Light.—It has been stated that the velocity of light varies with the substance or medium through which it passes. If, in a darkened room, a ray of light strikes the surface of water contained in a glass vessel, its course through the water may be traced, and its direction will be found to change at the point at which it enters the water. The

change in direction, called the refraction of the ray of light, is due to the fact that light travels with less rapidity in water than it does in air. Fig. 8 illustrates the refraction of a ray of light. The line *ab* represents the incident ray and *bc* the refracted ray, while the dotted line *bc'* shows the path the ray would have taken were the velocity of light the same in water as in air.

15. In Fig. 9 is shown a thick plate of glass through which a ray of light is supposed to travel, *B* being the point on the surface at which the ray *A* enters. The ray, instead of proceeding in the direction *C*, will be bent downwards toward point *D*, and on leaving the plate and entering the air on the
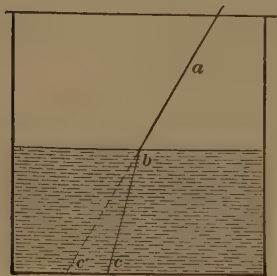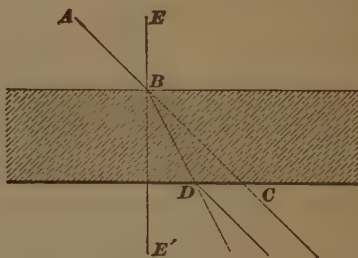
Fig. 8   Fig. 9

other side, will again be bent, but in an opposite direction, so as to travel parallel to the continuation of the original path, provided there is the same medium on the upper as on the lower side of the plate.

16. The general law of refraction may be expressed as follows: *When a ray of light passes from a rarer to a denser medium it is usually refracted toward a line perpendicular to the surface of the latter, and, conversely, when it leaves a dense medium for a rarer one, it is refracted away from a line perpendicular to the surface of the denser substance.* In the former case the angle of incidence is greater than that of refraction; in the latter it is less. Thus, the angle *A B E* is the angle of incidence, and *D B E'* is the angle of refraction.

The amount of refraction, for the same medium, varies with the obliquity with which the ray strikes the surface. When perpendicular to the latter, the ray passes without change of direction; and in other positions the refraction increases with the obliquity.

17. A ray of light *A*, Fig. 10, is represented as falling on the surface of a heavy glass plate at the point *B*. From this point let fall a perpendicular and continue it into the new medium, and around *B* as a center let a circle be drawn. Then, according to the general law of refraction, the refraction must be toward the perpendicular, in the direction *B C*, for example. Draw the lines *a a* and *a′ a′* from the points where the ray *A* cuts the circumference of the circle, at right angles to the perpendicular. These lines *a a* and *a′ a′* are the sines of the angles of incidence and refraction, respectively, for the ray *A*. If their lengths are

FIG. 10

compared by means of a scale, they will be found, in this case, to be in the ratio 3 : 2.
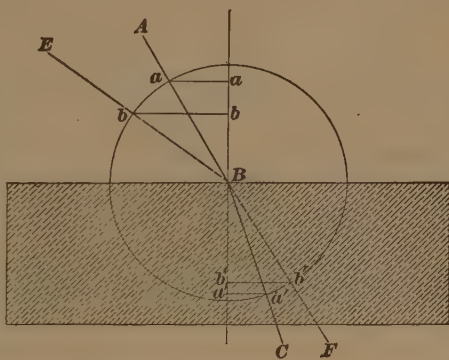
18. Let another ray of light *E*, Fig. 10, strike at the point *B* at a sharper angle to the surface than the ray *A*. It will be refracted in the same manner toward *F*, the bending being naturally greater because of the increased obliquity of the ray; but if *bb* and *b′ b′*, the sines of the new angles of incidence and refraction, are compared, they will be found to bear to each other the same ratio as before, that is, 3 : 2. The following statement of fact may therefore be made: *So long as the light passes from one to the other of two media, the ratio of the sines of the angles of incidence and refraction remains constant.*

19. Index of Refraction.—Different substances possess different refractive powers. As a rule, substances of greatest density possess this power to the greatest extent. The degree to which a medium refracts light depends on the velocity of light in that medium. As a means of measuring the extent to which light is refracted by any particular medium, air is taken as the standard medium and the velocities of light in other mediums are compared with the velocity in air. The numerical result of this comparison is known as the *index of refraction* of the refracting medium. However, it is much easier to measure the sines of the angles of incidence and refraction as shown in Fig. 10, the ratio of these sines being

TABLE I

INDEXES OF REFRACTION

Substance	Index of Refraction	Substance	Index of Refraction
Ice................	1.30	Carbon bisulphide.	1.70
Water.............	1.34	Garnet	1.80
Fluorspar.........	1.40	Phosphorus	2.20
Plate glass........	1.50	Diamond.........	2.50
Rock crystal.......	1.60	Lead chromate....	3.00
Chrysolite.........	1.69	Cinnabar.........	3.20

the index of refraction. Thus, the angle that the incident ray *A B* makes with the perpendicular has the sine *a a*, while the sine of the angle made by the refracted ray *B C* with the perpendicular is *a' a'*. These sines are in the ratio of 3 : 2 and the index of refraction of the medium, which in this case is plate glass, is $3 \div 2 = 1.5$. In Table I the indexes of refraction of several substances are given. It is assumed that the ray of light passes into the substances in question from the air.

20. Some Results of Refraction.—A stick partly submerged in water appears to be bent at the surface; the lower end of the stick and the part that is under water seem to be raised. Light travels in straight lines in any medium, pro-

vided that the density of that medium is uniform. This is not the case if from any cause the density is not uniform. The quivering of objects, when seen over heated coke or on a hot day, is due to unequal refraction, because the density of the air through which the rays of light are passing is constantly changing.

21. Total Reflection.—When a ray of light passes from one medium into another that is less refracting, as from water into air, the emerging ray is again bent from its course. Hence when light is propagated in a mass of water from C to A, Fig. 11, there is always a value of the angle of incidence $C\,A\,B$ such that the angle of refraction $B\,A\,D$ is a right angle, in which case the refracted ray emerges parallel to the surface of the water. This angle $C\,A\,B$ is called the *critical angle*, since, for any greater angle, as $E\,A\,B$, for instance, the incident ray can no longer emerge, but undergoes reflection. This is called *total reflection*, because the

FIG. 11

incident light is entirely reflected. The critical angle for water and air is $48\frac{1}{2}°$.
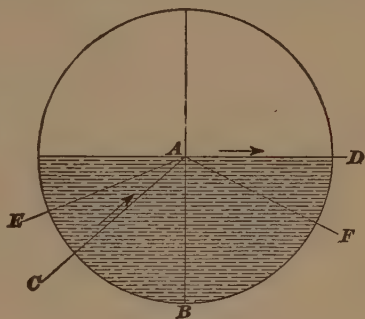
If a glass of water is raised above the head a position can easily be found in which the rays from the eye to every part of the under surface make a greater angle than $48\frac{1}{2}°$ with the normal. A brilliant mirror due to the total reflection of light will then be observed.

22. Transparent glass when finely ground loses its transparency. If the particles are arranged to form a layer having about the same thickness as an ordinary sheet of glass, the light is diffused at the surface of the mass, and the few rays that pass through the upper layer of fine particles are refracted in passing from the glass to the air between the surfaces of the particles; the result of this combined irregular reflection

and refraction is that the glass appears opaque. If a liquid whose refractive index is the same as that of glass is poured over the layer of ground glass, the result will be the same, in respect to the action of light, as if the glass were returned to its original, unground state; that is, powdered glass becomes in effect a glass plate and is again transparent.

23.   Prisms.—A prism is a portion of a transparent medium bounded by inclined plane surfaces.   When a ray of light falls on one of the inclined surfaces of a prism and passes through the body of the prism to another surface, from which it emerges, the change in the direction of the ray, instead of
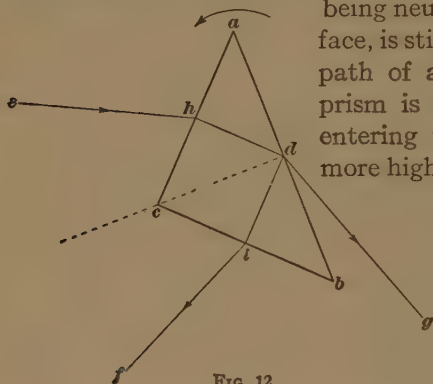

Fig. 12

being neutralized at the second surface, is still further increased.   The path of a ray of light through a prism is as follows: The ray on entering the prism passes into a more highly refracting medium and consequently is bent toward the normal (a line perpendicular to the surface of the medium). On leaving the prism, it is again refracted; but this time, as it passes into the air, which is less refractive than glass, it deviates from the normal.   The ray of light is thus refracted twice in the same direction; hence, in passing through a prism, it is deflected toward the base of the prism.

24.   Total Reflection in Prism.—A cross-section of a right-angled prism is indicated by *a b c*, Fig. 12.   A ray of light *e h* strikes the prism at *h* on the surface *a c* and is refracted; and when it strikes the surface *ab* at *d* it is split into two parts, one of which is transmitted and the other reflected.   If, now, the prism is slowly rotated to the left, a point will be reached at which the transmitted ray *dg* will disappear, while the reflected ray *dif* will become brighter.   It is at this point that total reflection begins.   Total reflecting prisms are frequently

made use of in optical instruments and when placed in the position shown in Fig. 13 they become the most perfect reflectors known.

25. Nature of Light.—Up until about the year 1800 it was generally thought that light consisted of streams of minute particles, called corpuscles, that were projected from all luminous bodies at enormous velocities. This theory of light, however, was unable to account for various phenomena later noted by scientists. Therefore, another hypothesis to the effect that light is a wave motion in an assumed medium called the ether has been accepted. The wave theory of light accounted for all the phenomena that had been previously explained by the corpuscular theory and for all other properties of light for which the corpuscular theory had no plausible explanation.
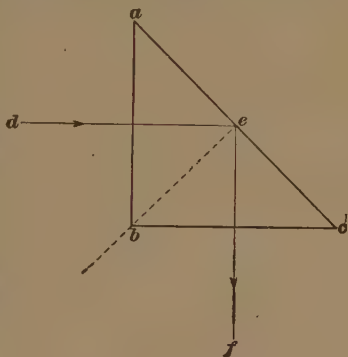
Fig. 13
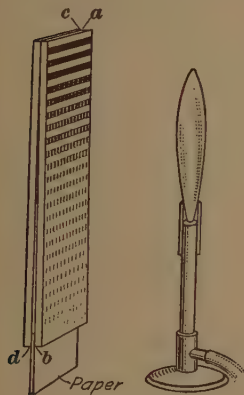
26. An experiment that supports the wave theory of light may be carried out as follows: Clamp together, in the manner shown in Fig. 14, two pieces of plate glass about 1 inch wide and 6 inches long. The inner edges a and c of the glass touch at the top, while the inner lower edges b and d are separated by the thickness of a thin sheet of paper, the arrangement forming a very thin air wedge between the inner glass surfaces. A yellow light is thrown on the glass plates by holding in the flame of a burner a piece of asbestos that has been soaked in a solution of salt. On viewing the glass plates from the side on which the burner is placed, fine black and yellow lines will be seen

Fig. 14

to pass over the nearer plate.   This effect is easily explained
by means of the wave theory.   The yellow light as it strikes
the two glass plates is partly reflected and partly transmitted
from all of their sur-
faces.   For the sake
of   simplicity,   only
those two surfaces *ab*
and *cd* that form the
air wedge will be con-
sidered, and these are
represented   enlarged
by lines *A B* and *C D*,
Fig. 15.   The vibra-
tions of the ether are
represented   by solid
and dotted wavy
lines.   The vibra-
tions producing the

Fig. 15

waves *ir* and *as* do not coincide, and the result is interference,
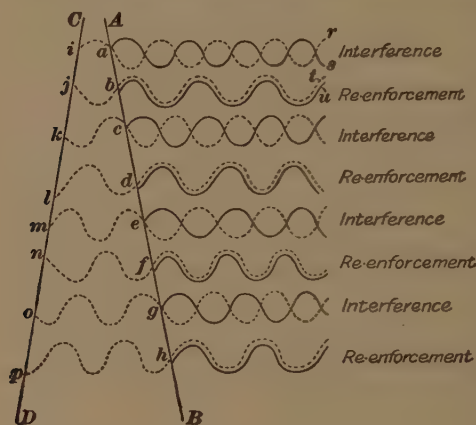which produces a dark band.   In the case of the waves *bu*
and *jt*, however, the vibrations of the ether producing them
do coincide, the result being reenforcement and a bright band.

SPECTRUM

27.   Dispersion.—When light is caused to pass through a
prism or a lens, it is frequently observed that the transmitted
light is tinged with the colors of the rainbow.   These colors are
due to refraction.   Suppose that a beam of light is admitted
into a dark room through a small hole in a shutter, and is
allowed to fall on a glass prism.   Refraction occurs, and if
a screen is put in the path of the rays, as shown in Fig. 16, a
band of color, called a *spectrum*, is formed on the screen.   This
separation of light into its component parts is called *dispersion*.
The light in passing through the prism is decomposed, and
on the screen it is possible to distinguish red (the least refracted
of the rays), orange, yellow, green, blue, indigo, and violet
(the most refracted).

Sir Isaac Newton was the first to investigate this phenomenon, and drew from it the inference that white light is composed of these seven primitive colors, the rays of which are differently refrangible by the same medium and are thus capable of being separated.

28. Bodies of the same refractive power, of course, do not equally disperse the differently colored rays to the same extent; if, for instance, the principal yellow or red rays are
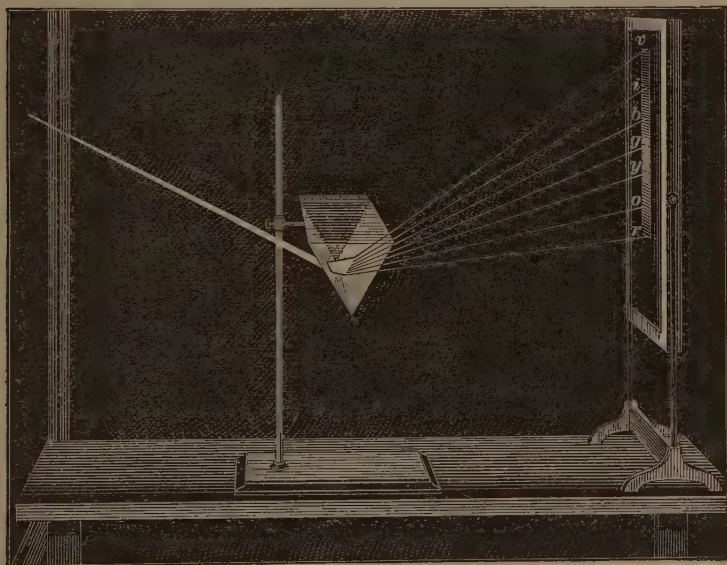
Fig. 16

equally refracted by two prisms of different substances, it does *not* necessarily follow that the blue or violet rays are also similarly affected. Hence, prisms of different varieties of glass or other transparent substances give, under similar circumstances, very different spectra, in regard to both the length of the image and the relative extent of the colored band.

29. Spectroscope.—In the spectrum produced by a glass prism, or that due to sunlight passing through raindrops giving

the effect known as a rainbow, the different colors do not form
distinct bands, but merge into one another or overlap each
other to a certain extent. The separation of the colors into
well-defined lines can be effected by means of an instrument
called the spectroscope, a simple type of which is shown in
Fig. 17. It consists of a tube a, called a collimator, at one
end of which is a narrow slit through which light passes to
a lens b at the other end of the tube. The lens renders the
rays parallel and directs them to the prism c, which refracts the
light at a certain angle, and the refracted light is then viewed
through the telescope d. The tube e contains a scale that may
be illuminated and light from it is reflected from one face of
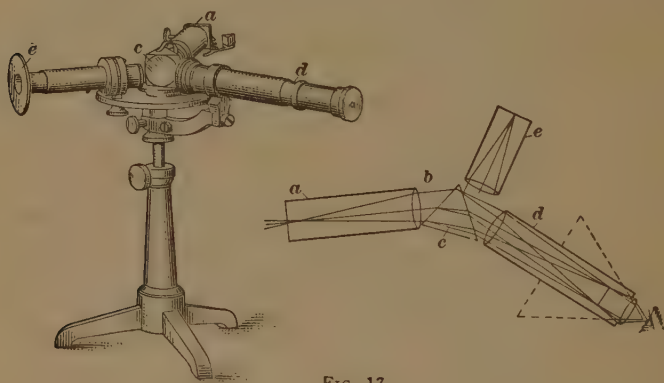
Fig. 17

the prism into the telescope along with the spectrum. In
this way the exact position occupied by the different colors
may be located, and for the same instrument they always
appear in the same place.

30. Spectrum Analysis.—When common salt, or sodium
chloride, is brought into the blue flame of a Bunsen burner,
the flame is colored yellow, and when that flame is viewed
through the spectroscope, a bright yellow line occupying the
position of the yellow portion of the spectrum will be observed.
If the instrument used is provided with a scale, this yellow
line may be definitely located. Then, if an unknown sub-
stance is held in the flame and the latter is viewed through

PLATE I

the spectroscope, the substance is identified as sodium if a bright yellow line appears at a point on the scale occupied by the sodium line. In a similar manner a great many substances that can be vaporized in the flame may be identified by the colors and positions of their spectral lines. Plate I shows the colors and positions occupied by the lines due to potassium (K), lithium (Li), and sodium (Na).

31. The colors imparted to a flame by most of the metals are not single colors, but are combinations of different colors. Thus, the violet flame of potassium contains red and violet rays and produces a dark red line near one end of the spectrum and a violet line near the other end. In the same way, the lithium flame, which appears bright red when viewed with the eye alone, contains some yellow rays, and its spectrum consists of a bright red line and a faint yellow line. When one substance exhibits two or more lines, each line is distinguished by means of a Greek letter. Thus, the two lines of potassium and lithium are distinguished by the letters α (alpha) and β (beta).

32. Fraunhofer's Lines.—If sunlight is allowed to fall on the slit of the spectroscope, numerous fine black lines of different degrees of breadth and shade are observed. These lines are always present, and always occupy exactly the same relative positions in the solar spectrum. They indicate the absence in sunlight of particular rays, and they may be considered as shadows or spaces where there is no light. They were discovered in 1802 by Dr. Wollaston, and subsequently were more thoroughly investigated by Fraunhofer, in 1814, so that they are generally known as Fraunhofer's lines. Some of them, in consequence of their relative positions, may always easily be recognized.

33. Fraunhofer's lines are absorption bands in the solar spectrum and are caused by the absorption of certain colors in sunlight by gaseous incandescent substances in the atmosphere of the sun. These substances absorb those colors which they themselves emit. Thus, the light given off by a flame in which a sodium compound is held is colored yellow,

and if the yellow flame is placed before the slit in the collimator and a beam of sunlight is passed through it, a black band appears in the yellow portion of the solar spectrum in the exact position in which the yellow line due to sodium appears when the sodium flame alone is the source of light. This indicates that the corresponding black line in the solar
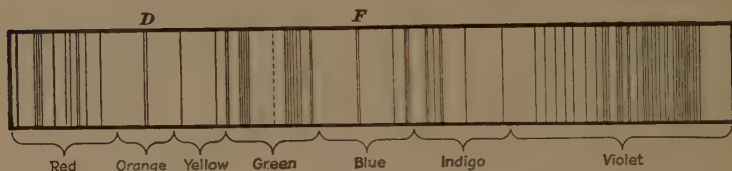
FIG. 18

spectrum is due to the passage of the rays of the sun through sodium vapor before they reach the earth. Fig. 18 is a condensed chart showing the positions of Fraunhofer's lines. When charted as shown, they serve as a convenient means of reference for colors. Thus, when a color is referred to as being *D* or *F* light, it is evident that it is orange or blue, respectively.

DOUBLE REFRACTION AND POLARIZATION

34. Double Refraction.—A large number of crystals possess the property of double refraction, which means that a ray of light passing through such crystals becomes split or divided into two rays; one, which is called the ordinary ray, follows the general law of refraction, while the other, which is known as the extraordinary ray, takes an entirely different, new course that depends on the position of the crystal. This remarkable property is found in nearly all bodies that crystallize in any other than the cubical form.   A transparent variety of calcite—found in Iceland, and hence known as Iceland spar —possesses this property in a marked degree. If a piece of this substance is placed on a sheet of white paper over an ink spot or any other mark, two images of the mark will be seen.

35. Polarization.—It is believed that ether vibrations which produce light waves take place in all directions at right

angles to a line along which the light is moving. It is possible, however, to remove the vibrations in certain directions by
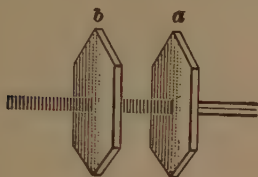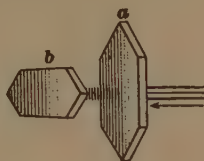
passing a ray of light through crystals of Iceland spar or tourmaline. In Fig. 19 a ray of light is shown passing unhindered through two crystals a and b of tourmaline; but when the crystal b is turned through an angle of 90°, as in Fig. 20, the ray passing through the crystal a is completely cut off by the crystal b. This is known as a plane polarized ray, because the vibrations of the ether producing such polarized light are confined to a single plane.

36. The final statement of the preceding article may be made clearer by reference to Fig. 21 (a) and (b). Assume that a ray of light is moving in a direction perpendicular to the plane or surface of the paper and that c in (a) is its point of intersection with the plane. Then the lines radiating in all directions from c represent the directions in which the ether particles producing this ray of light are vibrating in this plane. After the ray has passed through a crystal of tourmaline, all the vibrations except those in one plane have been removed and the directions in which the ether parti- cles vibrate, in the first plane considered (the plane of the paper), will be represented by the straight line in (b).
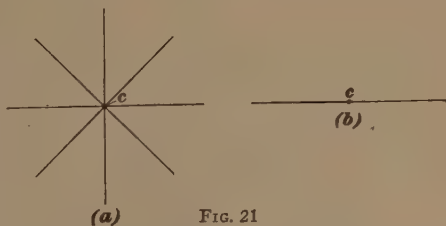
(a) Fig. 21

37. Two pieces of apparatus are used in the study of polarized light. They are called the polarizer and the analyzer, each of which consists of

two crystals of Iceland spar cut in a certain manner and then joined together by means of Canada balsam cement. These built up prisms are called Nicol prisms, after their inventor. In Fig. 19, *a* is the polarizer and *b* the analyzer, since the latter serves to detect polarization.

38. Rotary Polarization.—If a ray of light that has been polarized by passing it through a Nicol prism or a crystal of tourmaline is passed through a solution of some such substance as sugar, the plane of the polarized ray is rotated so that the
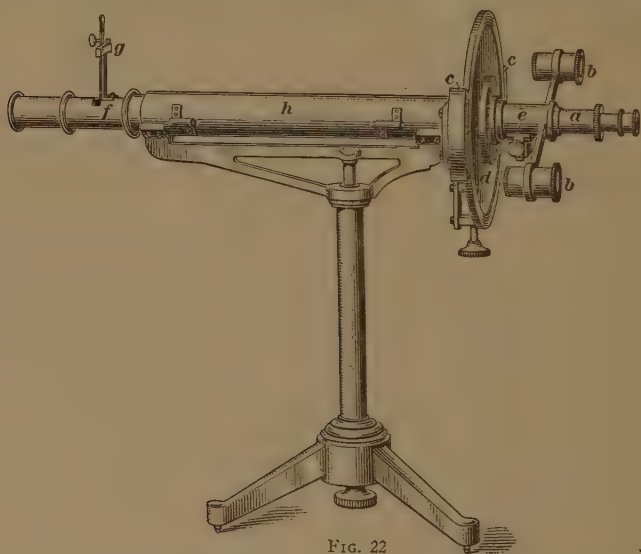
Fig. 22

light is enabled to pass through an analyzer, which in the absence of the sugar solution it could not penetrate. Substances producing this effect are said to be *optically active*, or to have the power of *rotary polarization*. This may be illustrated as follows: Suppose two Nicol prisms are so arranged that light which is polarized by the first is stopped by the second. If, now, a substance having the power of rotary polarization is placed between the two prisms, the analyzer will become transparent. This is caused by the substance placed between the prisms rotating the plane of polarization. The

analyzing prism must then be rotated to the right or the left in order to become opaque again.   The direction of rotation and the magnitude of the angle through which the analyzer is rotated is obtained in this manner.

FIG. 23

39.   Construction of Polarimeter.—The polarimeter, shown in Fig. 22, is an instrument used for the detection and measurement of polarization.   In the illustration, a represents a telescope, and the magnifying glasses b insure accurate reading of the degree of rotation from the verniers or scales c on the revolving dial d. An enlarged section of the vernier and dial is shown in Fig. 23.   The analyzer e, Fig. 22, is fixed to the dial and to the telescope and is adjusted by means of the beveled screw indicated by the line just below e.   The movable polarizer f has a graduated segment g of a circle attached to it.   Fig. 24 shows the tube used to hold the solution that is to be examined.
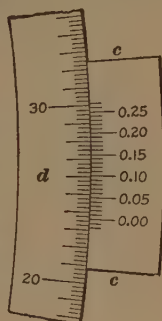
40.   The internal construction of the polarimeter is shown by the diagram in Fig. 25.   The telescope lenses are indicated
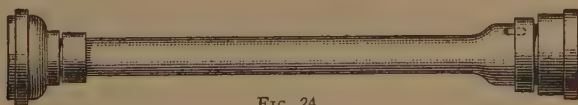
FIG. 24

at a, b, and c, the Nicol prism d serves as an analyzer, and the tube e contains the solution under examination.   At f is placed a semicircular quartz plate (represented by the shaded portion f' of the small circle), the thickness of which is such

FIG. 25

that the light passing through it is retarded.   In this manner, two beams of polarized light are obtained, the other beam

passing through the space not obstructed by the quartz plate. This space is represented by the unshaded portion f'' of the circle. The polarizer is shown at g and the lens h renders parallel the rays from the source of light i, which may be a sodium flame.

41. Operation of Polarimeter.—The polarimeter is first placed in such a position that the end containing the polarizing prism is next to the source of light and about 6 inches from it. A tube filled with distilled water is placed between the polarizer and the analyzer by lifting the hinged cover h, Fig. 22. With the tube in place, the telescope is focused on the vertical line that divides the field of view, represented by the vertical line between the semicircles f' and f'', Fig. 23, and the analyzer is rotated so as to get unequal illumination of the two halves. Next, the analyzer is rotated to determine the point at which both sides of the field of view are equally illuminated. This is known as the zero point, and the position of the analyzer should be read from the verniers. This done, the tube of distilled water is removed and a tube containing a solution to be examined, such as a sugar solution, is placed in the instrument. On looking through the telescope it will be found that one half of the field of view is now darker than the other. The analyzer is rotated until both halves of the field again become equally illuminated and a new reading is taken from the verniers. The difference between the two readings gives the degree of rotation. Having thus determined the angle of rotation due to the sugar solution, the percentage of sugar in the sample may be calculated by the aid of formulas and tables.

42. Reading Angle of Rotation.—The method of reading the exact angle of rotation from the verniers and dial of the polarimeter is easily explained by referring to Fig. 23. The graduated dial d rotates inside the stationary vernier c. Suppose that when the polarimeter has been adjusted to show equal illumination of each field, the dial and the vernier are in the relative positions shown. It will be seen that the zero

line of the vernier is between 23.5 and 23.75 on the dial. Again, the line indicating .16 on the vernier coincides with a line on the dial. The exact reading is therefore 23.5+.16 =23.66°.

ELECTRICITY

STATIC OR STATIONARY ELECTRICITY

43. **Generation of Electricity by Friction.**—The ancient Greeks knew that when the substance which we now call amber was vigorously rubbed it would attract small pieces of paper and other light objects. It is now known that this property is not possessed by amber alone, but by a great number of substances, among which may be mentioned glass, sealing wax, sulphur, and hard rubber. Amber was called electron by the Greeks, and so Gilbert, who in 1600 discovered that other substances could be used in place of amber, gave the name of *electrification* to the effect produced by rubbing these substances. Electricity produced in this way by friction is called static electricity.

44. **Positive and Negative Electricity.**—If a glass rod that has been electrified or charged with electricity by rubbing it briskly with a piece of silk is suspended by a thread, and a second electrified glass rod is brought near it, it will repel the suspended rod. On the other hand, if a hard rubber rod that has been electrified by rubbing it with flannel is brought near the suspended glass rod, the latter is strongly attracted. Again, if an electrified rubber rod were suspended and a second electrified rubber rod were brought near it, the suspended rod would be repelled.

45. It is evident that the electrifications or charges that have been imparted to the glass rods are not the same as those imparted to the rubber rods. Therefore, it is assumed that there are two kinds of electricity, and so the charge imparted to the glass rod is designated as *positive* and that to the rubber rod as *negative*. From the experiments described, it is seen

that like or similar electrical charges repel each other while unlike or dissimilar charges attract each other. In other words, positive charges repel positive charges, and negative charges repel negative charges, but positive and negative charges attract each other.

46. Detection of Electricity.—Whether or not a substance is charged with electricity, and the nature of the charge, whether positive or negative, may be determined by the use of an instrument called an electroscope, illustrated in Fig. 26. It consists essentially of two gold or aluminum leaves a and a' hung from a brass rod b. The leaves are enclosed in a glass case that may be brought to a truly horizontal position by
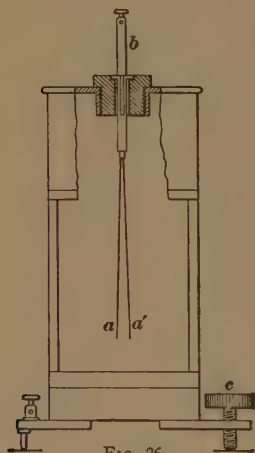
Fig. 26

means of the leveling screw c. When a charged glass rod is brought near the brass rod of the electroscope, the leaves separate as shown, and when the glass rod is withdrawn, the leaves assume their original positions. If the glass rod is brought in actual contact with the brass rod, however, the leaves separate and remain apart. The electroscope is then positively charged and if a positively charged body is brought near it, the leaves spread farther apart; but if a negatively charged body is brought near it, the leaves fall toward each other. Thus, by the use of the electroscope, it is possible to tell whether a substance is positively or negatively charged.

47. Conductors and Non-Conductors.—If the brass rod of a positively charged electroscope is connected by a metallic wire to a metal ball a short distance removed from it, a positively charged body brought in contact with the metal ball will cause the leaves of the electroscope to spread still farther apart. This shows that the charge on the positively charged body has been transmitted through the ball and the wire to the electroscope. If a stick of wood or a silk thread

is substituted for the metallic wire, and the experiment is repeated, no movement of the leaves of the electroscope will be noticed, showing that the charge was not transmitted or conducted to the electroscope. Thus it is seen that certain substances are conductors of electricity while others are non-conductors. Among the former may be classed the metals and solutions of different substances, such as ordinary table salt and some acids. Among the non-conductors the most prominent are sulphur. glass, rubber. dry air, and pure water. It should be understood, however, that no sharp line can be drawn between conductors and non-conductors, since the former offer some resistance to the passage of electricity and the latter all conduct electricity to some extent.

ELECTRICAL UNITS

48.   Ampere.—The passage of electricity along a conductor may be likened to the flow of water through a pipe, and this analogy is helpful in defining the units used in making electrical measurements. Water flowing through a pipe may be measured in any quantity for any given unit of time, as, for instance, in gallons or cubic feet per second, per minute, etc. In dealing with electricity, however, it is customary to consider the quantity that passes along a conductor per second. This quantity is called the *coulomb*; but the term is rarely used, since the time element involved is part of another unit, the *ampere*. which is commonly used. Thus a coulomb per second is equivalent to an ampere. The ampere expresses quantity of electricity just as one gallon per minute expresses quantity of water.

49.   Volt.—The quantity of water that will flow through a pipe in any unit of time depends largely on the pressure that causes the water to flow, which is usually measured in pounds per square inch. The quantity of electricity passing along a conductor per second, or simply the number of amperes, also depends on the pressure that causes the current to flow. This pressure is known as *electromotive force*, abbreviated *e. m. f.*

The electrical unit of pressure is called the *volt*. The comparison between water flowing through a pipe and electricity passing along a conductor may be carried further. The difference in electrical pressure that may exist between widely separated points on a conductor is called the difference in potential between these points. Likewise, a difference in pressure exists between two points in a water tower, if one is located at the bottom and the other near the top.

50. Ohm.—When a valve in a water pipe is closed, the flow of water ceases, but the pressure of the water on the closed valve remains. If the valve is opened just a little, a small quantity of water flows, but the pressure does not vary. In the same way, when a switch in a circuit through which electricity is passing is opened, the flow of current stops; but the pressure causing it to flow is still the same. If the switch is replaced by a poor conductor of electricity, only a small quantity of electricity will flow, but the pressure behind it will be the same as though the proper switch were used. It is evident, therefore, that something besides pressure determines the rate of flow of water or electricity. This something is called resistance, and in electrical measurements the unit of resistance is called the *ohm*. Volts and amperes may be directly measured by the use of instruments called voltmeters and ammeters, and knowing the current strength in amperes and the pressure in volts, the resistance in ohms can be easily calculated.

51. Ohm's Law.—Ohm's law may be stated as follows: The quantity of electricity that passes along a conductor is equivalent to the pressure behind the current divided by the resistance of the conductor. In other words

$$\text{Current} = \frac{\text{pressure}}{\text{resistance}}$$

In electrical units this becomes

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$$

If I represents the current strength in amperes, E the electromotive force in volts, and R the resistance in ohms,

$$I = \frac{E}{R}$$
$$E = I\,R$$
$$R = \frac{E}{I}$$

Thus, knowing any two of the three values, E, I, and R, the third may easily be found.

PRIMARY BATTERIES

52. Primary Cell.—A primary, voltaic, or galvanic cell, as it is variously called, is an apparatus for converting chemical energy directly into electrical energy. The cell consists of two conducting elements immersed in a solution, called the electrolyte, that acts chemically on one element only or on one more than on the other. If the two elements or poles of the cell are joined by a continuous metallic wire or circuit, an electric current will flow in one direction through the metallic circuit as long as the circuit remains complete, or closed, provided the chemical action is sufficient to maintain the electromotive force.

53. About the year 1786, Galvani, an Italian physiologist and physicist, discovered that frogs' legs, suspended from an iron support by a copper wire, made violent movements when in contact with both the iron and the copper. Galvani supposed the movements due to a separation of positive and negative electricity at the junction of the nerves and the muscles.

Volta, another Italian physicist, showed that two dissimilar metals were necessary to the production of the phenomenon. In 1799, he constructed a form of battery known as *Volta's pile*. Disks of zinc, wet cloth, and copper were piled up in the order given, thus producing a battery having a large number of couples joined in series and from which a considerable electromotive force was obtained. Later, Volta changed the form of the pile by substituting cups of salt water for the wet

cloth, inserting copper and zinc strips in the liquid of the cups, and formed a battery of cells by joining the copper of one cup to the zinc of the next cup.

Fabroni, an Italian biographer, was perhaps the first to recognize that chemical reactions occur when dissimilar metals are immersed in water and brought into contact at some point, and stated (about 1791) that he believed the electric phenomena produced to be due to the slow combustion of a metal.

54. Action of Primary Cell.—A very simple primary cell would be one in which the metallic conducting elements, or electrodes, consisted of zinc and copper, and the liquid in which they were immersed was dilute sulphuric acid. A cell

Copper (Cu) Zinc (Zn)

($H_2O +$ H_2SO_4)
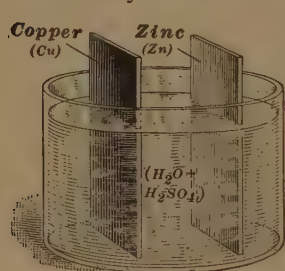
FIG. 27

of this type is illustrated in Fig. 27; however, before attempting to describe the chemical action that takes place in the cell, as the result of which electricity is caused to flow, it will be well to learn the chemical symbols and formulas shown. The symbol for copper is Cu and that for zinc is Zn, while the formulas for water and sulphuric acid are H_2O

and H_2SO_4, respectively. The formula H_2O shows that water is composed of two parts of hydrogen (H_2) and one part of oxygen (O). The formula H_2SO_4 shows that sulphuric acid is composed of two parts of hydrogen, one part of sulphur (S) and four parts of oxygen.

55. When sulphuric acid is dissolved in water, its molecules break up into two parts, namely, hydrogen (H_2) and the sulphate radical (SO_4). These two parts are called *ions* and they carry electrical charges. The charge carried by the hydrogen ion differs from that carried by the sulphate radical, and to distinguish them the hydrogen ion is said to carry a positive charge and the sulphate radical a negative charge. The dilute solution as a whole does not show any electrical properties, since the positive and negative ions it contains exactly neutralize each other.

56. When a zinc plate and a copper plate are immersed in the sulphuric-acid solution and connected to an outside conductor a of electricity, as shown in Fig. 28, chemical action begins immediately. The sulphuric acid attacks the zinc and causes zinc ions to go into solution. The zinc ions, as well as the ions of other metals that dissolve in acids, bear positive charges as they leave the zinc plate and the corresponding negative charge is deposited at the zinc plate by the sulphate ion. The zinc ion now replaces the hydrogen (H_2) in sulphuric acid (H_2SO_4), forming zinc sulphate ($ZnSO_4$), and gives up its positive charge to the hydrogen ion. The hydrogen ion then migrates to the copper plate and gives up its positive charge. The copper and zinc plates being connected by an outside conductor, a current passes from the copper to the zinc, or from the positive plate to the negative. The plates thus lose their charges, which allows the chemical action on the zinc to proceed. When the plates are not connected by a conductor of electricity, chemical action goes on until the plates become charged, and then it ceases.
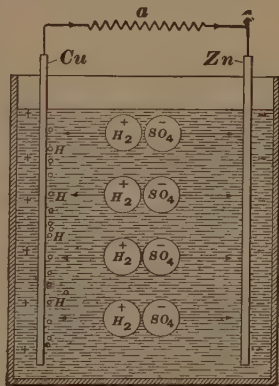
Fig. 28

57. Polarization.—When the simple cell just described is put into use, it delivers a current of certain strength. Within a very short time, however, the current grows weaker, and a point may be reached at which the cell refuses to function at all. The cause is the accumulation of hydrogen on the positive copper plate, and when it occurs the cell is said to have become polarized. Hydrogen gas conducts electricity very poorly, and its presence on the copper plate increases the internal resistance of the cell, to such an extent that a large part of the energy released as the result of the action between zinc and sulphuric acid is used to force the current through the cell itself.

58. Depolarizers.—In order that a cell may continue to give efficient service, the hydrogen ions that arrive at the positive plate must be removed. This may be accomplished in a variety of ways and each method gives rise to a different type of cell. The method commonly employed to remove hydrogen from the positive copper plate is to introduce into the solution, or electrolyte, a chemical compound that contains available oxygen, which then unites with the free hydrogen and forms water.

59. Local Action.—Another factor that works to destroy the efficiency of a cell is local action. It usually takes place on the negative plate of the cell and is almost always caused by impurities in the material of which the negative plate is made. Local action can be illustrated and explained by assuming that the impurity imbedded in the zinc is carbon. Then, when the positive and negative plates are placed in the electrolyte and an outside circuit is made, the positively charged hydrogen ion, instead of migrating to the copper plate, goes to the particle of carbon imbedded in the zinc plate and gives up its charge to the carbon. In this manner a small cell within a cell is set up, and the action of the zinc-carbon couple consumes the zinc but does not produce an electromotive force at the terminals of the cell. The current produced merely flows from the carbon to the zinc. To avoid local action, only pure materials should be employed; but as this is practically impossible, amalgamation of the zinc plates is resorted to, to cover up the impurities.

60. Amalgamation of Zincs.—In many types of cells, local action may be very much reduced and in some cases practically prevented by submitting the zinc to the process of amalgamation. By this means the iron, lead, and other impurities are separated from the zinc and made harmless. To amalgamate the zinc, it is first dipped in dilute sulphuric acid to clean the surface; then a little mercury is poured over it and rubbed into the surface with a brush. When finished, the surface should be as bright as silver. Another way to amalgamate zinc is to immerse it in an acid solution

of mercuric nitrate. A small part of the zinc is changed to zinc nitrate and liberates mercury, which combines with the remaining zinc. The result by either method is that the whole of the zinc is covered with a pasty amalgam.

61. Where it is frequently necessary to amalgamate a large number of zincs, a solution consisting of nitric and hydrochloric acids and mercury may be used. To amalgamate the zinc, it is immersed in the solution for 1 or 2 seconds, then quickly removed to a dish of clean water and rubbed with a brush or cloth, when it will be found to be covered with a fine, even coat of mercury. This solution can be kept in a covered jar and used many times.

It is a peculiarity of the amalgam that it does not leave the zinc when the latter dissolves, but immediately attaches itself to fresh portions of the zinc plate. The surface will therefore appear bright and clean for a very long time.

62. Open-Circuit and Closed-Circuit Cells.—It has already been stated that, when the simple primary cell is continuously used, the current which it delivers gradually becomes weaker due to polarization. If, however, the cell is allowed to rest for a sufficient time, it gradually becomes depolarized; that is, the hydrogen that has accumulated on the positive copper plate rises to the surface of the electrolyte and escapes. The point to be noted concerning this type of cell is that it does not contain a depolarizer and consequently gives efficient service only when used intermittently; therefore, it is known as an open-circuit cell.

On the other hand, the primary cell that gives efficient service when used continuously contains a depolarizer, and is used on a closed circuit only; that is, the electrical energy it supplies is always being used. Therefore, it is known as a closed-circuit cell. It cannot be successfully used intermittently, as on an open circuit, because the nature of the depolarizer employed is such that the cell may be ruined by its chemical action when it is allowed to stand idle. In other words, if there is no hydrogen present for the depolarizer to work on, it soon causes changes in the electrolyte, with the

formation of new products that attack the elements composing the cell.

63. Sal-Ammoniac Cell.—The sal-ammoniac cell is made up of the elements zinc and carbon, which are immersed in an electrolyte consisting of an ammonium-chloride (NH_4Cl) solution. The electromotive force of this cell (without a depolarizer) varies from 1.3 to 1.4 volts, but when supplying a current of .2 ampere or more, the electromotive force soon drops and seldom regains its original value. When the cell is being used the ammonium chloride acts on the zinc and forms zinc chloride ($ZnCl_2$), ammonium (NH_3) and hydrogen (H_2).
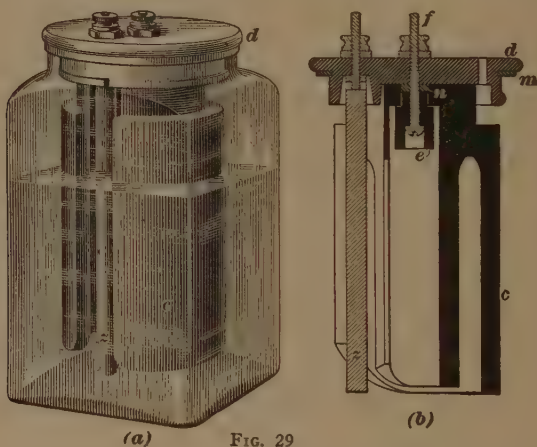
Fig. 29

To recharge an exhausted cell only a new zinc rod and a fresh solution of sal ammoniac are required. The carbon, which may have the shape of a cylinder, should be well soaked in water and exposed to the air and sun to remove the salts with which the pores become clogged. There are a great variety of sal-ammoniac cells in use for ringing bells, gas lighting, and doing other intermittent work. They are alike in principle, but their mechanical construction differs somewhat.

64. Law Open-Circuit Cell.—Ammonium chloride is used as the electrolyte in the Law open-circuit cell, shown in

Fig. 29 (a). In this cell the carbon electrode c is in the form of two hollow cylinders, one enclosing the other, as shown in section in (b), giving the carbon element a very large surface. Each cylinder has a wide vertical slit in which the zinc rod z hangs, being suspended from the cover d, which is made of compressed insulating material. A rubber band m under the cover produces a close fit between the cover and the jar. The terminal f is fastened by a nut on the top of the cover and makes contact through the carbon piece e with the cylinder c. This piece e is a separate piece of carbon and makes contact with the cylinders c only through a shoulder, the tightness of the joint depending on the nut on top of the cover. A very soft rubber washer n forms a tight joint beneath the piece e.

65. Many other forms of carbon and zinc elements are used, but the shape of the carbon has comparatively little to do with the satisfactory working of the cell provided that the surface exposed to the liquids is very large; care and good design in the construction are more important. The element should be of such shape as not to be easily broken in transit, and, being usually molded into shape under pressure, should be of such proportions that it is cheap to make. The carbon should be made as porous as possible. Thus, the area of the internal circuit of the cell is made large, and at the same time advantage is taken of the slight depolarization occurring with a porous carbon of large surface, due to the oxygen that porous carbon absorbs from the air, and with which some of the evolved hydrogen combines. This depolarizing action takes place slowly, and, therefore, hydrogen forms on the carbon if a considerable current is taken from the cell, thus increasing the internal resistance. In intermittent work this is not objectionable, as the hydrogen is soon absorbed when the external circuit is opened. The connection between the binding post and the carbon in reliable cells is so made that there is little or no trouble from corrosion by capillary ascent of the solution. Corrosion may be caused by carelessly spilling the solution over the top and terminals.

Being very cheap and of common occurrence, a sodium-chloride solution is sometimes used as an electrolyte. The electromotive force of a zinc-sodium chloride-carbon cell is about 1.08 volts, which is somewhat lower than that obtained when ammonium chloride is used.

66. Bunsen Cell.—Nitric acid, being rich in available oxygen, has been used as a depolarizing agent. Its use is objectionable from the fact that, when deprived of a part of its oxygen, it gives off a gas, nitric oxide (NO), which, on combining with the oxygen of air, becomes nitrogen peroxide, (NO_2), a very disagreeable and even poisonous, corrosive gas; consequently, good ventilation is essential where cells with

(a)   (b)
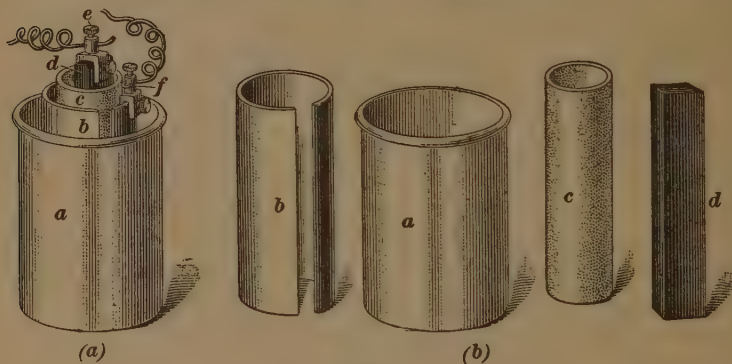
Fig. 30

this depolarizer are used. The principal cell using this depolarizer is the Bunsen cell illustrated in Fig. 30 (a). The details, shown in (b), consist of a vessel a, of stoneware or glass, containing dilute sulphuric acid, a cylinder b of amalgamated zinc, a porous vessel c that contains nitric acid (HNO_3), and a carbon rod d. The cell is assembled by placing the zinc cylinder b in the vessel a. The porous vessel c, containing nitric acid, and the carbon rod d are then placed in the cylinder b. The carbon and zinc elements are provided with binding posts e and f, from which the current is taken.

67. With commercial nitric acid having a specific gravity of about 1.33, the electromotive force of the Bunsen cell is

1.89 volts ordinarily; if pure nitric acid (specific gravity 1.53) is used, the electromotive force is increased to about 1.96 volts. About .35 volt is due to the action of the depolarizer. Variations in the density of the nitric acid affect the electromotive force of the cell only slightly, until the specific gravity of the solution falls to about 1.23. Below this point the acid has little or no effect as a depolarizer, although the liquid still contains about 30 per cent. of nitric acid.

68. As commercial nitric acid is most frequently used in the Bunsen cell, only a small portion of water is required to dilute it to a point where it cannot be used. In fact, where commercial acid is used, only about 13 per cent. of the actual amount of the pure acid in the solution can be utilized. In cases, however, where acid of 1.4 specific gravity is used, a much greater percentage can be utilized. The water formed at the positive element by the process of depolarization, therefore, is disadvantageous on account of its dilution of the depolarizer.

The proportions of the two acids in the cells are about three of electrolyte to one of depolarizer, the depolarizer being of a specific gravity of about 1.33 to 1.4; with these proportions the cell will maintain its electromotive force (within about 10 per cent.) for several days on a closed circuit. The average internal resistance of a quart-size cell (as ordinarily constructed) is about 1 ohm. Such a cell will give about 1.25 amperes continuously until some material is exhausted. Where as large a current as this cell will give is not required, the following non-fuming solution may be used, all parts being taken by weight: Nitric acid (density 1.42), one part; chromic acid, three parts; sulphuric acid, six parts; water, five parts.

69. Bichromate Cells.—An important depolarizer used in cells having a liquid depolarizer consists of a mixture of potassium bichromate ($K_2Cr_2O_7$) and sulphuric acid. Sodium bichromate ($Na_2Cr_2O_7$) or chromic acid (CrO_3) may be used in place of the potassium salt. Bichromate salts have a large proportion of available oxygen and so are good depolarizers A type of bichromate cell much used at one time for experi-

mental and laboratory work is the Grenet cell, shown in Fig. 31. It consists of a bottle-shaped glass jar with a hard-rubber or porcelain cover, from which two flat carbon plates C are suspended, parallel to and a short distance from each other. Between them hangs a zinc plate Z supported by a sliding rod R, which may, and preferably should, be drawn up, when the cell is not in use, until the zinc is entirely out of the liquid, so that local action may be prevented. It is held in any position by the thumbscrew T. On the top of the brass rod is a binding post B_1; the other terminal of the cell is the binding post B, which is connected to the two carbon plates.
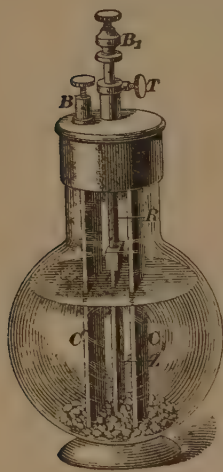
Fig. 31

70. The electrolyte for bichromate cells may be made of three parts of potassium bichromate, dissolved in eighteen parts of water, to which is slowly added four parts of sulphuric acid, all parts by weight. The electromotive force is 1.9 to 2.1 volts. At ordinary temperatures, variations in the proportion of bichromate in the solution, within moderate limits, do not change the electromotive force or the internal resistance very much. Variations in temperature change the internal resistance, but not the electromotive force, the internal resistance decreasing as the temperature increases. With the proportion of sulphuric acid and potassium bichromate in the solution just given, the sulphuric acid is first exhausted. Theoretically, for an equal life of both substances in the electrolyte, the correct proportions should be seven parts, by weight, of sulphuric acid, to three parts of potassium bichromate, which proportion is often used. In fact, however, it is more important to keep up the strength of the depolarizer, that is, the bichromate, so the first proportion will give better results.

71. If sodium bichromate is used in place of potassium bichromate, the percentages of salt and acid may remain about

the same. The sodium salt is more soluble and hence a denser solution can be used; therefore, replenishing is required less frequently. Crystals of the double sulphate of sodium and chromium do not form as with the bichromate solution; thus, the cells are more easily cleaned. Furthermore, sodium bichromate may be dissolved in cold water to form any density desired, which cannot be done with potassium bichromate. To make the solution for a battery, it is only necessary to place powdered sodium bichromate in the water and add slowly the sulphuric acid, with constant stirring. The mixture is ready for use as soon as it has cooled.

The battery solution, using chromic acid, is made by pouring $5\frac{1}{2}$ pints of water upon 6 ounces of chromic acid and then adding slowly, with stirring, $\frac{1}{2}$ pint of concentrated sulphuric acid.

72. Plunge Batteries.—Cells of the bichromate type are often arranged to form what is called, in the United States, a plunge battery, and in Europe, Poggendorff's battery. Such a battery does not differ in principle or material from the Grenet cell, but it usually consists of several cells connected to give an electromotive force of 6 to 10 or more volts. All the elements are suspended in such a manner that they may be raised out of, or lowered into, the liquid.

73. Care of Bichromate Cells.—As a rule, the electrolyte needs renewing when its color is a dark green. Should the color of the electrolyte be orange, and the cell yet show some weakening in its action, the addition of some sulphuric acid may improve it. If bichromate cells are used daily the electrolyte will need renewing in from 3 to 6 weeks. The elements should be removed and suspended in a jar with cold water in which about a tablespoonful of salt has been dissolved. Most of the impurities in the carbon will have been dissolved when the water has assumed a greenish hue. After a thorough soaking, the elements are rinsed off in cold water and thoroughly dried with a cloth; they are then ready to be replaced in the battery. The importance of lifting the zincs out of the electrolyte when not in use should not be forgotten.

74. Trouble with bichromate plunge batteries is sometimes due to poor contact between the carbon and its metal terminal. In such cases the flat surfaces of the metal against which the carbon rests appear to make no connections. Good, clean, and firm contact should be made between the metal and the carbon, and to preserve this condition when once made, by excluding the battery solution from the joints, the whole, extending down the carbons about 1 inch, should be painted with a good insulating paint. Many carbons, when they have been in the solution a while, have a tendency to crack or split at the connections and if not stopped the crack will extend, in the course of a little time, through the carbon; insulating paint put on the joint as directed entirely prevents this cracking.

75. Daniell Cell.—The Daniell cell uses zinc for the negative plate; for the electrolyte, a solution (usually) of zinc sulphate ($ZnSO_4$); for the positive plate, copper; and for the depolarizer, a solution of copper sulphate ($CuSO_4$). Sometimes, in setting up the cell, dilute sulphuric acid is used instead of the zinc sulphate, but this soon forms a solution of zinc sulphate; hence, the result is the same as if the zinc sulphate were used originally. The electromotive force of the Daniell cell is given several values by different investigators, ranging from 1.059 to 1.079 volts. The original form of the Daniell cell consisted of a glass jar, into which the zinc, in the form of a cylinder, was placed. Inside the zinc was a porous cup containing the cathode, a strip of sheet copper. The porous cup was filled with the copper-sulphate solution and the outer jar with the zinc-sulphate solution.

To prevent the gradual weakening of the depolarizer, it is usual to put a considerable amount of copper-sulphate crystals (commonly known as blue vitriol or bluestone) into the porous cup. As the liquid weakens, the crystals are gradually dissolved. Several modifications of the form of the original Daniell cell are in use. Some of them are designed to keep up the supply of copper sulphate as it is used.

76. The specific gravity, at ordinary temperature, of a saturated zinc-sulphate solution is about 1.44, while that of a

saturated copper-sulphate solution is about 1.20; hence, if saturated solutions of these salts are used, the zinc-sulphate solution will be considerably heavier than the other. It has been found, however, that the best results are obtained from a saturated solution of copper sulphate, used with a solution of zinc sulphate diluted to have a specific gravity of about 1.10. The considerable difference in weight between the two solutions has led to their arrangement, one over the other, in the cell, the heavier copper sulphate being at the bottom.

77. Gravity Cells. Daniell cells that depend on the difference of the specific gravities of the two liquids to keep them apart, are called gravity Daniell cells, or simply *gravity cells*. As long as a current is flowing through the cell, the chemical action keeps the boundary line of the two liquids sharply defined; but when the current ceases to flow, the solutions gradually mix, and

Fig. 32

the copper sulphate, coming in contact with the zinc anode, sets up local actions, which cause a deposit of copper (appearing as a finely divided black coating) on the zinc, and a consumption of the zinc itself. To prevent this action, these cells should be used only on a circuit that is closed nearly all the time.

78. Crowfoot Cell.—The form of gravity Daniell cell most used in the United States is the familiar crowfoot cell, shown in Fig. 32, Z being the zinc from the shape of which the cell gets its name; C is the copper, which is connected to the external circuit by the wire W, which is insulated where it

passes through the liquid. When the cell is set up the copper
cathode is surrounded with copper-sulphate crystals. In
the standard form of this cell the jar is 6 inches in diameter
and 8 inches high. The copper element is made from three
pieces of thin sheet copper 2 inches wide and 6 inches long
riveted together in the middle; the outside pieces are then
spread out, forming a six-pointed star. To the middle strip
is riveted a piece of No. 16 insulated copper wire. The zinc
usually has the shape shown and weighs 3 pounds. Many
other forms of zincs are used more or less. The cell furnishes
a working electromotive force of 1 volt. For continuous work-
ing, the most economical current output is about $\frac{1}{4}$ ampere.
Its internal resistance varies considerably, depending on its
condition, but 3 ohms may be taken as an average value.

79. Setting Up Crowfoot Cell.—To set up the crowfoot
gravity cell, unfold the copper strip so as to form a star and
place it in the bottom of the jar. The point where the copper
connecting wire is riveted to the copper electrode, or positive
element, should be near the bottom of the cell, and the
insulated covering on the wire should come close to the riveted
joint. Suspend the zinc about 4 inches above the copper by
hooking the trip, or lug, on the side of the jar. The lug has a
hole in it to receive a connecting wire. The method of sus-
pending other forms of zincs will be evident from their con-
struction. Pour sufficient clean water into the jar to cover
the zinc and drop in the copper sulphate in small lumps.
About 3 pounds is the proper amount to put in a cell to be
used for heavy, continuous work.

80. The internal resistance may be reduced and the
battery made immediately avaiiable by drawing about $\frac{1}{2}$ pint
of solution of sulphate of zinc from a battery already in use,
and pouring it gently into the jar; or, when this cannot be done,
by putting into the jar 4 or 5 ounces of pulverized sulphate of
zinc previously dissolved in a cup of water. If there is no
hurry for the cells, do not put in the zincs until the solutions
have had time to settle to their normal conditions, which will
require at least 24 hours. This prevents or reduces the for-

mation of a black deposit on the zinc. When there is much of this black deposit, remove the zinc and brush or scrape it off. If no zinc sulphate is added in setting up the cell, it will be necessary to short-circuit the cell for some time (24 hours will not be too long) before it will be in good condition.

81. Caring for Gravity Cells.—Blue vitriol should be dropped into the jar as it is consumed, care being taken that it goes to the bottom and does not settle on the zinc. The need of the blue vitriol is shown by the fading of the blue color, which should be kept at least as high as the top of the copper, but it should never reach the zinc. There should always be some bluestone crystals in the bottom of the jar.

After the battery has been started, no further attention is required, except to keep it supplied with bluestone and water, until the quantity of sulphate of zinc in solution has become too great. As long as the battery continues in action, there is an increase of the quantity of sulphate of zinc in solution in the upper part of the jar. When this becomes too dense (above 1.15 specific gravity), it will be necessary to draw out a portion of the top of the liquid with a battery syringe or a cup and replace it with clear water.

82. A hydrometer is convenient for the purpose of testing the strength of the solution. It usually consists of a small glass tube, the lower end of which is enlarged and partly filled with fine shot or mercury. The tube, when placed in a solution, floats in a vertical position. Some hydrometers are graduated by experiment with solutions of known specific gravity so that the scale indicates the specific gravity directly. When graduated according to the Baumé scale the hydrometer is floated in water, and the point on the stem on a level with the surface of the water is marked 0°; then it is floated in strong undiluted sulphuric acid, and the corresponding point marked 65°. The intervening space is divided into 65 equal divisions, called degrees.

83. When the specific gravity of the solution in the gravity cell is less than 1.115 (15° on the Baumé hydrometer scale), there is too little sulphate of zinc; when it is 1.260 or over

(25° to 30° Baumé), there is too much in solution, and it must be diluted. When the zincs become coated so as to interfere with the proper action of the battery, they must be taken out, scraped clean, and washed. A gravity cell can be maintained in good condition by keeping it on a closed circuit about 60 per cent. of the time. If kept on open circuit too long a time the solutions mix and the cell is not ready for immediate use.

84. Cleaning Gravity Cells.—Cells that are used constantly should be cleaned out about once every 3 months. To do this, carefully remove the zinc, clean it by scraping with a knife, and wash it with plenty of water. Pour the clear liquid into a separate jar, leaving behind the oxide and dirt that may have gathered in the bottom of the jar. Now take out the copper, clean it and the jar, and throw away the sediment. Replace the copper, put around it some bluestone crystals, pour the clean liquid back into the jar, replace the zinc, and, without disturbing the liquid any more than is necessary, add enough water to cover the zinc. The battery will soon be ready for use, and short-circuiting the cell or battery should bring it into condition very rapidly. Some question the advisability of using any of the old solution over again, preferring to use only fresh solution, but this requires short-circuiting the battery for at least 24 hours, in order to bring it into working order, consuming both time and battery material. A fresh solution will, without doubt, give the best results where time and expense are not important.

85. The condition of a gravity cell may be judged from its appearance. When the cell is in good order, the solution is bright blue in color, the blue fading to a colorless solution before reaching the zinc. The batteries should not be allowed to freeze, for while frozen, the current is very much reduced or altogether stopped. Below 65° or 70° F., the internal resistance of a battery increases very rapidly. A battery works much more vigorously while warm, for heat is a promoter of chemical action. The connections should be kept free from dirt and corrosion in order to allow the current a low-resistance path through them.

86. Creeping of Salts.—If no precautions are taken to prevent it, after a time the sides of the battery jar, above the liquid, may be covered with crystals of salts, which may even extend over the top of the jar. These crystals, besides giving a dirty appearance to the cell, represent a considerable loss of salt from the cell and may also cause leakage of current. This creeping of salt is a phenomenon of capillarity. The solution, by capillarity, rises a little distance on the sides of the jar, and as the water evaporates the crystals of salt are deposited. More of the solution then arises through the salt crystals and creeps a little higher and more crystals are deposited. This action continues until the salt gradually creeps over the sides of the jar.

87. Strong solutions creep worse than dilute ones. The white zinc sulphate that creeps over the jars is a very fair conductor of electricity when moist, and if it extends from cell to cell, may cause considerable leakage and consequent waste of current and battery material. The creeping of salts in this and many other types of cell over the side of the glass jar is generally prevented by coating the upper part of the jar with paraffin. To do this, dip the inverted jar to a depth of about $\frac{1}{2}$ inch in a shallow dish of melted paraffin. Tip the jar sidewise, otherwise the air confined in the inverted jar will not allow the melted paraffin to rise to coat sufficiently the inside of the jar.

88. Oil on Gravity Cells.—Oil on top of the solution will not only prevent the creeping of salts, provided it is poured on before the creeping commences, but it will also prevent evaporation of the solution. The oil makes it more difficult to clean the cell, but it saves the time that would otherwise be required for replenishing the cells with water. The oil may be removed with sand and a wet cloth. The advisability of using it is a disputed question and depends on local conditions. As common oil is very apt to rot the insulating covering the wire running through it to the copper element, only a good quality of petroleum lubricating, or heavy paraffin, oil should be used.

89. Leclanché Cell.—The Leclanché cell is a well-known and widely used cell. Its positive element (negative terminal) is zinc, usually in the form of a rod; the electrolyte is a solution of ammonium chloride (sal ammoniac); and the negative element (positive terminal) is carbon, surrounded by manganese dioxide (MnO_2) (also called black oxide, or peroxide, of manganese), which is the depolarizer. This being in the form of a coarse powder, it is usually contained in a porous cup, which allows free access of the electrolyte to the depolarizer and negative element. Fragments of crushed coke (or carbon in other forms) are often mixed with the manganese dioxide to decrease the resistance of the contents of the porous cup.
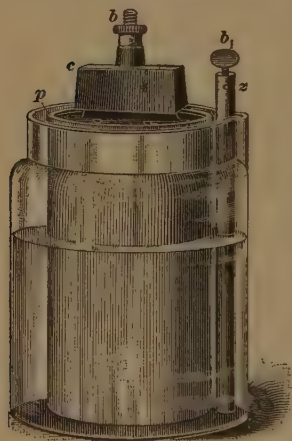

Fig. 33

90. The usual form of Leclanché cell is shown in Fig. 33. The porous cup p contains the manganese dioxide and the carbon electrode, which projects from the top of the cup, and to which a binding post b is attached. The binding post is often placed on the side instead of the top of the carbon. The glass jar is circular, with a contracted top, in which a slight recess is usually formed to contain the zinc z. The top of the zinc is provided with a binding screw b_1, which serves as the negative terminal of the cell, b being the positive terminal. The top of the jar is coated with paraffin to prevent the creeping of salts over the top of the jar.

91. The cell shown in Fig. 33 has the following dimensions: Jar, $4\frac{1}{2}$ inches in diameter, $6\frac{1}{2}$ inches high; zinc, $\frac{3}{8}$ inch in diameter, $6\frac{1}{2}$ inches high; porous cup, 3 inches in diameter, $5\frac{1}{2}$ inches high; carbon, $\frac{5}{16}$ inch by $1\frac{1}{2}$ inches by 6 inches high. The weight of the zinc rod is about 3 ounces, about two-thirds of which is below the level of the liquid. There is about 16 ounces of peroxide in the porous cup, and it requires 4 or 5 ounces of ammonium chloride to make sufficient solu-

tion for this size of cell. For each ounce of zinc consumed in the cell, 2 ounces of manganese dioxide and 2 ounces of ammonium chloride must also be consumed; so, from the amount of these materials contained in the cell, it follows that there is enough peroxide in the porous cup to last while four zincs are being consumed, while the ammonium chloride will not last longer than one zinc. As the zincs are usually replaced when eaten away to about $\frac{1}{8}$ inch or $\frac{1}{16}$ inch diameter, the solution need not be replaced until about two zincs have been consumed, and the contents of the porous cup will last as long as five or six zincs. The consumption of zinc in the Leclanché cell is about 23 ampere-hours per ounce of zinc, and as about $1\frac{3}{4}$ ounces of each zinc rod may be consumed, the life of each zinc is then about 40 ampere-hours. The electromotive force of this type of cell varies from 1.4 to 1.7 volts and its internal resistance varies from .4 to 4 ohms.

92. Dry Cells.—The name dry cells is applied to cells in which the electrolyte is carried in the pores of some absorbent material, or combined with some gelatinous substance, so that the cell may be placed in any position without spilling the liquid. They are usually made with zinc and carbon elements. The zinc usually forms the outside of the cell, being made into a cylindrical can; in the center of this is the carbon, surrounded by its depolarizing compound. The space between the elements is filled with some absorbent material, such as mineral wool, asbestos, sawdust, blotting paper, etc., and the whole, including the depolarizer, is then soaked in the exciting liquid; or, the exciting liquid is mixed with a hot solution of some gelatinous body, such as Irish moss, which mixture is poured into the cell; on cooling, it forms a soft jelly. The first method of preparation is most used.

93. It is quite necessary for dry cells to have a depolarizer, as otherwise they would have to be made open to allow the hydrogen gas to pass off, which would also allow the small amount of water they contain to evaporate. To prevent this latter action, these cells are sealed with some resinous compound. The zinc can is covered with pasteboard to insulate

it. Owing to the presence of the absorbent material, the actual amount of liquid in these cells is comparatively small, and the sealing, if imperfect, allows the water to evaporate, in which case the cell ceases to act.

The materials used in dry batteries are usually kept secret by their manufacturers; they all, however, answer to the foregoing description as to construction, and the best types use the same materials as the Leclanché battery; that is, a zinc anode, ammonium-chloride electrolyte, manganese-dioxide depolarizer, and carbon cathode.

94. The dry cell is extremely convenient on account of its portability and the fact that it needs no attention until a new one is required. Even if not used, the terminal potential gradually falls and the internal resistance rises. This is said to be
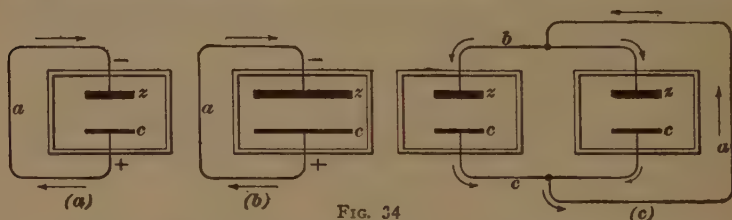

Fig. 34

due, not so much to the drying up of the paste, as to the increase in internal resistance caused by a partial consumption of the manganese dioxide and the accumulation between the zinc can and its inside paper lining of non-soluble impurities of zinc and various other salts formed by electrolytic action. Even the best dry cells will not usually remain in good condition longer than 3 years, while the poorer ones depreciate considerably if stored 1 or 2 years.

Dry cells of ordinary size should not be used where a current exceeding about .2 ampere is required. A dry cell of standard size should give an output of 30 ampere-hours, for at such an output the voltage across the cell terminals on closed circuit is, on the average, 1 volt.

95. Connecting Cells in Parallel.—Joining similar cells in parallel amounts to the same thing as using larger plates in a single cell, as can be seen by referring to Fig. 34. In view (c), z

are positive elements or plates (negative terminals) of two similar cells and c the negative elements or plates (positive terminals) in the same cells. As all the positive plates are joined together by conductors when in parallel, the plates might as well be joined together directly and placed in one vessel, as shown in (b) (without wires), as far as the result is concerned. If all the plates of one kind are joined together end to end, the result is one plate of twice the area of a plate of a single cell; when the plates are so joined, it is more convenient to place them in a single cell. As the resistance of a cell varies inversely as the area of the plates (because the area of a plate is equivalent to the sectional area of the liquid across which the current flows), the resistance of the large cell as shown in (b), or that of the two small cells joined in parallel,

as shown in (c), will be one-half that of one of the small cells acting alone, as shown in (a). As the two cells joined in parallel are equivalent to a single cell having plates twice the size, the two cells in parallel will naturally have the same electromotive force as the single large cell,
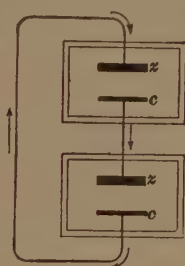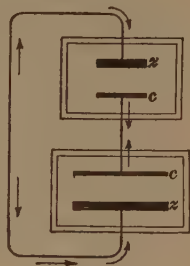

FIG. 35   FIG. 36

which is the same as that of one of the small ones. Hence, any number of similar cells joined in parallel will have the same electromotive force as a single cell no matter what its size may be, but a resistance equal to that of one cell divided by the number of cells.

96. Connecting Cells in Series.—Two cells joined in series are shown in Fig. 35. Not only are the electromotive forces of the cells to be added together, but their resistances also. As the current must go through both resistances one after the other, the length of the fluid column is doubled and consequently the resistance also. Hence, when similar cells are joined in series, the resistance must be that of one cell

multiplied by the number of cells.   Furthermore, the electro-
motive force of each cell is superimposed on that of the others
in the series, and therefore the total electromotive force of the
battery is equal to the sum of all the electromotive forces; or, in
the case of similar cells, is the electromotive force of one cell
multiplied by the number of cells.

In Fig. 36, the cells of Fig. 34 (a) and (b) are joined in the
manner indicated.   There will be no current, because the
electromotive force of each cell is the same and they act in
opposition to each other.   That one cell is much larger than
the other does not alter this fact.   The arrows indicate the
direction in which the electromotive forces tend to send a
current.

EXAMPLE 1.—If the electromotive force of each cell in Fig. 35 is 1.1 volts
and the internal resistance of each cell is .6 ohm, what will be the electro-
motive force and the internal resistance of the battery?

SOLUTION.—The electromotive force of the battery will be 1.1×2
$= 2.2$ volts.   Ans.

The internal resistance of the battery will be $.6 \times 2 = 1.2$ ohms.   Ans.

EXAMPLE 2.—If the electromotive force and internal resistance of each
cell in Fig. 34 (c) is 1.1 volts and .6 ohm, respectively, what will be the
electromotive force and the internal resistance of the battery?

SOLUTION.—The electromotive force of the battery, as similar cells are
joined in parallel, will be equal to that of one cell, namely, 1.1 volts.   Ans.

The internal resistance, as the total area of two similar plates joined
together is twice that of one plate, will be $.6 \div 2 = .3$ ohm.   Ans.

97. If several cells, all of the same size and kind, are
connected in series, their total internal resistance will equal
the resistance of one cell multiplied by the number of cells,
and their total electromotive force will equal the electromotive
force of one cell multiplied by the number of cells; if they are
all connected in parallel, their total resistance will be equal
to the resistance of one cell divided by the number of cells,
while their total electromotive force will be equal to that of
a single cell.   From this it follows that if the external resistance
is very small, increasing the number of cells in series will not
increase the current in the external circuit appreciably, as the
resistance increases nearly as fast as the electromotive force;

while if the external resistance is great, increasing the number of cells in parallel will not appreciably increase the current flowing, as the total resistance is not much altered, while the electromotive force remains the same.

98. Internal Resistance.—The internal resistance of a cell depends on the area of the elements in contact with the solution, on the average distance from one element through the solution to the other element, and on the resistance of the solution between the plates. The internal resistance will be inversely proportional to the average area of the surfaces of the elements in contact with the solution, directly proportional

TABLE II

ELECTROCHEMICAL EQUIVALENTS OF METALS

Metal	Grams Consumed or Deposited Per Hour Per Ampere
Gold................................	3.677
Silver...............................	4.025
Copper	1.186
Aluminum............................	3.369
Nickel..............................	1.094
Zinc................................	1.219

to the average distance between the elements, and directly proportional to the resistance of the solution.

99. Electrolysis.—The rate at which the negative plate of a battery is consumed or decomposed by the electrolyte determines the current that the battery supplies. When chemical action ceases, the battery does not supply current. When the battery supplies 1 ampere per hour, a certain quantity of the negative plate, which may be made of zinc, is consumed, and this quantity increases directly with the current. Thus, if 2 amperes is supplied per hour, twice as much zinc will be consumed as in the first case. It has already been shown how zinc from the negative plate dissolves in the

electrolyte and forms zinc sulphate. If, then, a current of 1 ampere from some outside source were passed back through the battery for 1 hour, the same quantity of zinc from the electrolyte would be deposited on the negative plate as was consumed in generating a current of 1 ampere for 1 hour. Again, if 2 amperes is passed through the cell for an hour, the quantity of zinc deposited will be doubled. This is essentially the process of electrolysis, which may be defined as the breaking up of an electrolyte by passing an electric current through it.

100. Electrochemical Equivalent.—The quantity of a metal that is consumed per hour when a cell supplies a current of 1 ampere, or the quantity of a metal that is deposited per hour by electrolysis when 1 ampere is caused to flow back through a cell, is called the electrochemical equivalent of the metal. Table II gives the electrochemical equivalents of some of the metals.

STORAGE BATTERIES

101. Nature of Storage Battery.—The storage cell, secondary cell, or accumulator, as it is variously called, is fundamentally the same as a primary cell, but differs in that when discharged, either wholly or partly, the storage cell can be restored to its original state, or charged, by passing current through it for a sufficient length of time in the reverse direction. The material of the electrodes that undergoes chemical changes during charge and discharge, called the active material, is generally supported on the surface or in the openings, or pockets, of a conducting framework, or grid. The grid with its active material is called a plate. Each electrode in a storage cell consists of a plate or of a group of plates connected in parallel. The plates of the positive electrode alternate with those of the negative, in order to provide the shortest path for the current through the electrolyte.

102. Types of Storage Cell.—Two types of commercial storage cell are in use: the lead-sulphuric-acid cell, sometimes called, simply, the lead cell, and the nickel-iron-alkaline cell, known also as the nickel-iron, or Edison, cell. The names

are derived from the chemical natures of the electrodes and electrolytes.

103. Lead-Sulphuric-Acid Cell.—In the lead-sulphuric-acid cell, the grids, both positive and negative, are of lead or of lead-antimony alloy. The active material of the positive plate when the cell is fully charged is lead peroxide, a chemical compound of lead and oxygen. The active material of the fully charged negative plate is metallic lead in a spongy, porous state. The electrolyte is a solution of sulphuric acid, formed by mixing 1 part of pure concentrated acid with 2.5 parts, by weight (4.5 parts by volume), of distilled water. The specific gravity of the electrolyte—that is, the ratio of the weight of a given volume to that of an equal volume of water—is about 1.3.

104. The lead and the oxygen in lead peroxide are chemically combined into a substance from which neither can be separated except by a chemical process. The lead peroxide undergoes such a process during a discharge of the cell; half of the oxygen is transferred from the positive to the negative plate, producing lead monoxide, another chemical compound of lead and oxygen, on each plate. At the same time, the sulphuric acid is decomposed into water and a gas called sulphur trioxide; this gas combines with the lead monoxide, forming lead sulphate on each plate. The active material on each plate of a fully discharged lead cell is therefore lead sulphate; and the electrolyte has become weakened because of the presence of additional water formed by the decomposition of some of the sulphuric acid. Not all the sulphuric acid disappears from the solution, because, originally, more than enough acid was added to convert all the active material on the plates of the fully charged cell into lead sulphate. The excess of acid is necessary because pure water alone is a nonconductor.

105. During charge, the reactions are reversed; the acid is restored to the electrolyte; the active material of the positive plate is oxidized to lead peroxide, and that of the negative

plate is reduced to spongy lead; and the chemical conditions of a fully charged cell are gradually reestablished.

It will be noted that the specific gravity (strength) of the electrolyte decreases during discharge and increases during charge, thereby furnishing an indication of the state of discharge of the cell.

106. In the fully charged nickel-iron cell, the active material of the positive plate is nickel peroxide, and that of the negative plate is finely divided metallic iron. The electrolyte is a dilute solution of potassium hydroxide, or caustic potash. A small quantity of lithium hydroxide is added to the electrolyte to improve the capacity of the cell.

During discharge, part of the oxygen of the nickel peroxide is dissociated and transferred to the negative plate, where it combines with the iron to form ferrous (iron) oxide; but the composition of the electrolyte remains unchanged. Unlike the electrolyte of the lead cell, the potassium hydroxide serves merely as a carrier of oxygen from one electrode to the other. When the cell is fully discharged, the active material of the positive plate is nickel oxide, and that of the negative plate, ferrous oxide.